

United States Patent

[11] 3,560,758

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Claremont, Calif.
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 [45] Patented **Feb. 2, 1971**
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2,774,276	12/1956	Glasser et al.	250/226X
3,060,790	10/1962	Ward.....	250/226X
3,069,971	12/1962	Simmon et al.	250/226X
3,120,782	2/1964	Goddard et al.	250/226X
3,127,517	3/1964	Kestenbaum.....	250/220
3,133,201	5/1964	Rock.....	250/226
3,255,305	6/1966	Chatten.....	328/115
3,003,388	10/1961	Hunter et al.	250/226X

OTHER REFERENCES

Hambleton: International Dyer & Textile Printer; Jan. 20, 1967 pp 102— 105

Primary Examiner—Walter Stolwein

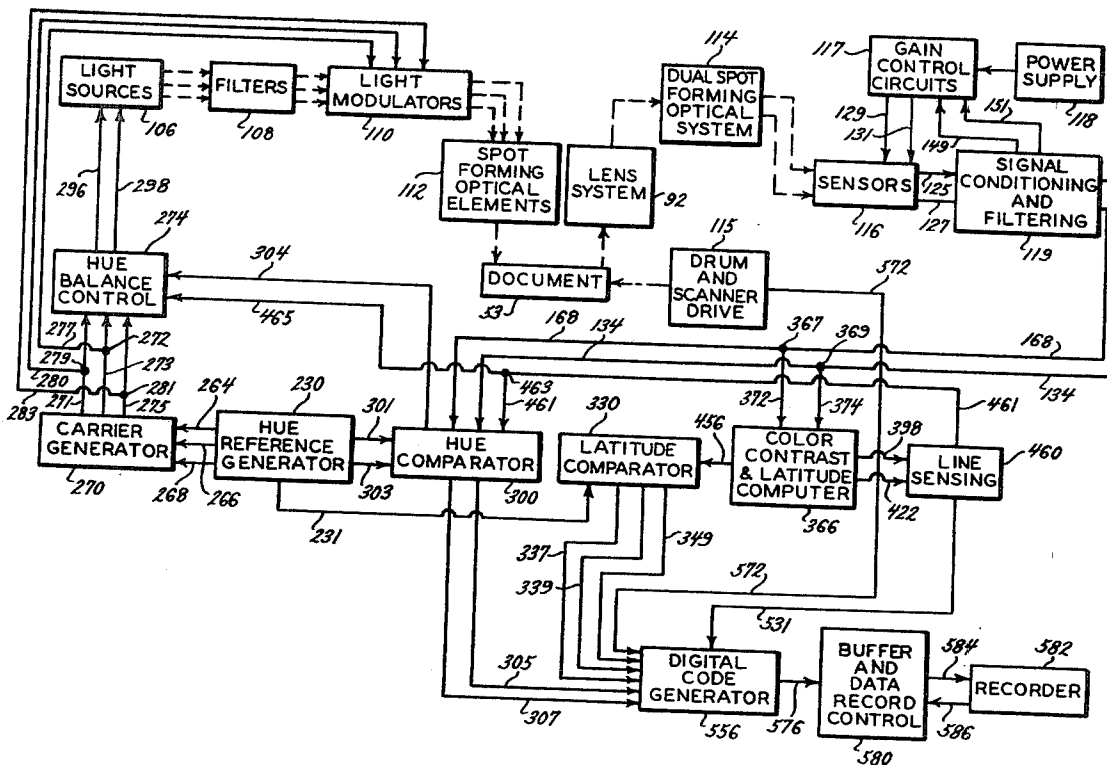
Attorney—Kingsland, Rogers, Ezell, Eilers and Robbins

[54] **COLOR IDENTIFICATION SYSTEM TAKING INTO ACCOUNT THE COLOR AND REFLECTING OF THE BASE MATERIAL**
34 Claims, 57 Drawing Figs.

[52] U.S. Cl. **250/226,**
 250/719; 356/176
 [51] Int. Cl. **G01j 3/34**
 [50] Field of Search..... 356/173,
 174, 176, 177, 178, 186, 191, 193, 195; 250/226,
 220, 209, 225

[56] **References Cited**
UNITED STATES PATENTS
 2,669,902 2/1954 Barnes..... 350/14

ABSTRACT: The color identification system takes the color and the reflectivity of the base material of a printed or drawn colored document into account as it identifies the pigments which define the various differently colored areas of that document, and thus is a relative color identification system; and that color identification system can accurately identify the pigments which define the various differently-colored areas on that document by classification of each color, which is detected, as being within a range of colors, which includes all colors that can be expected to result from one pigment.



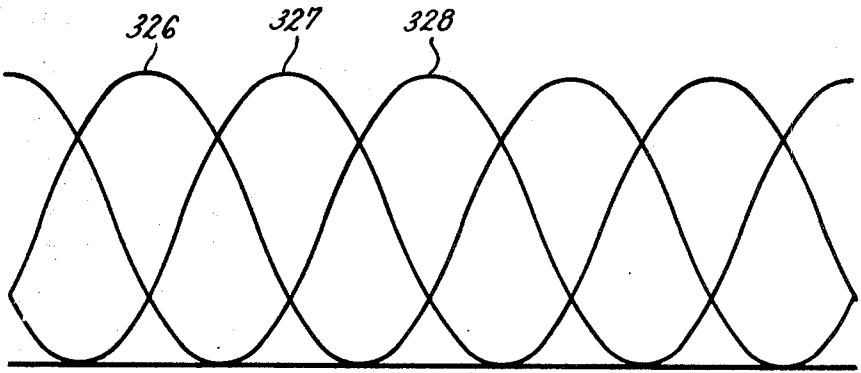
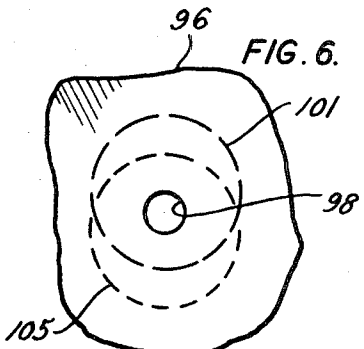
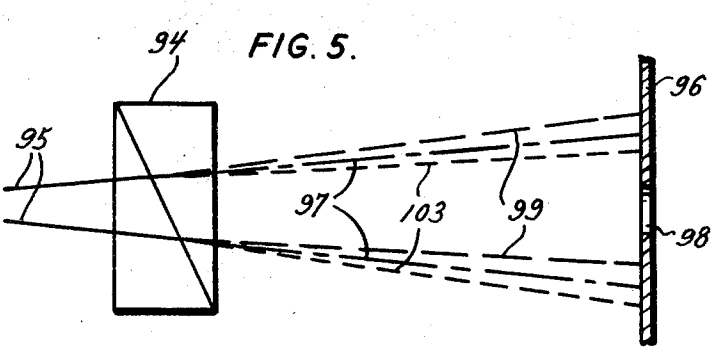
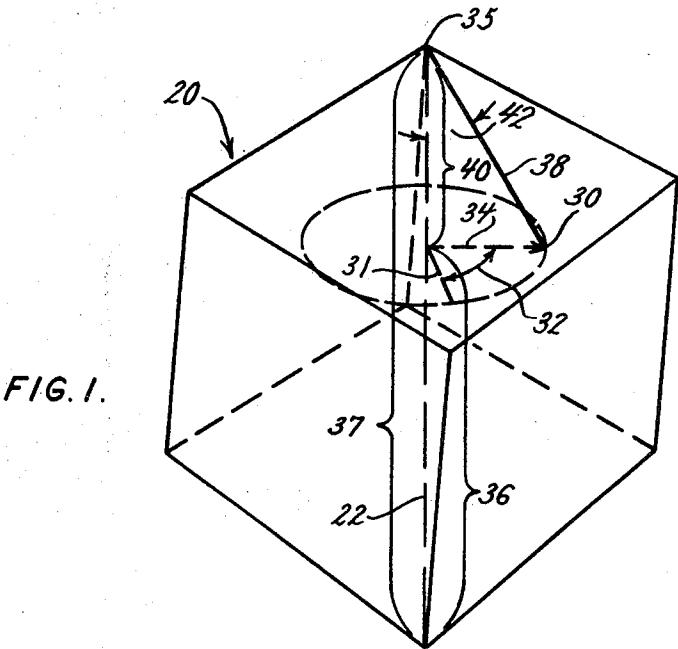


FIG. 7.

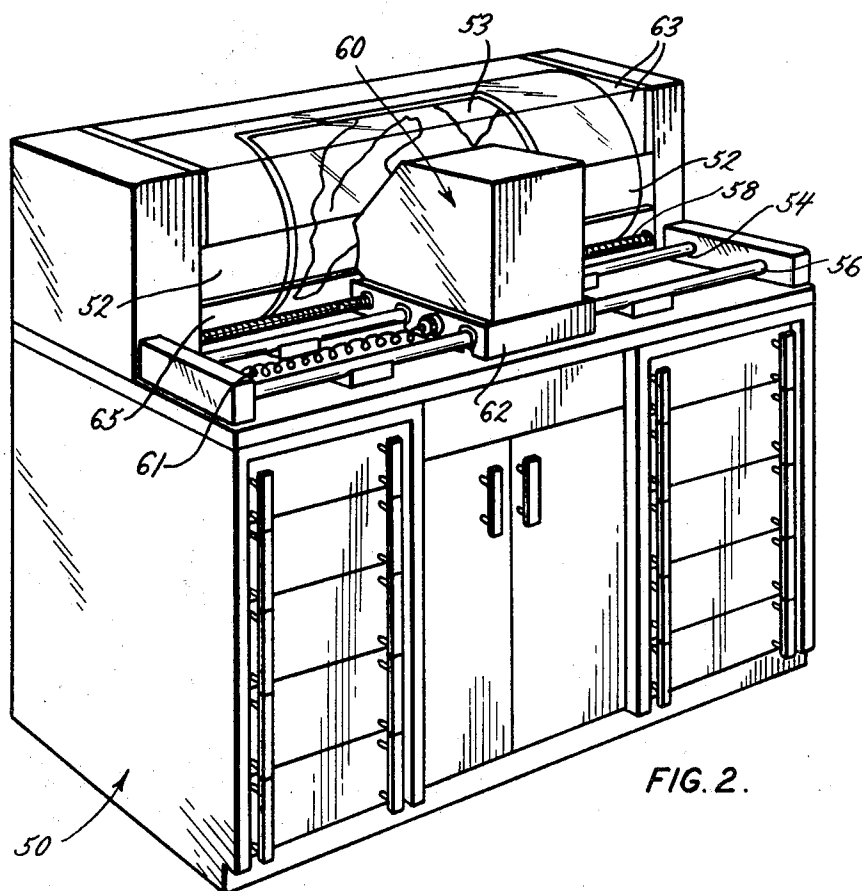


FIG. 2.

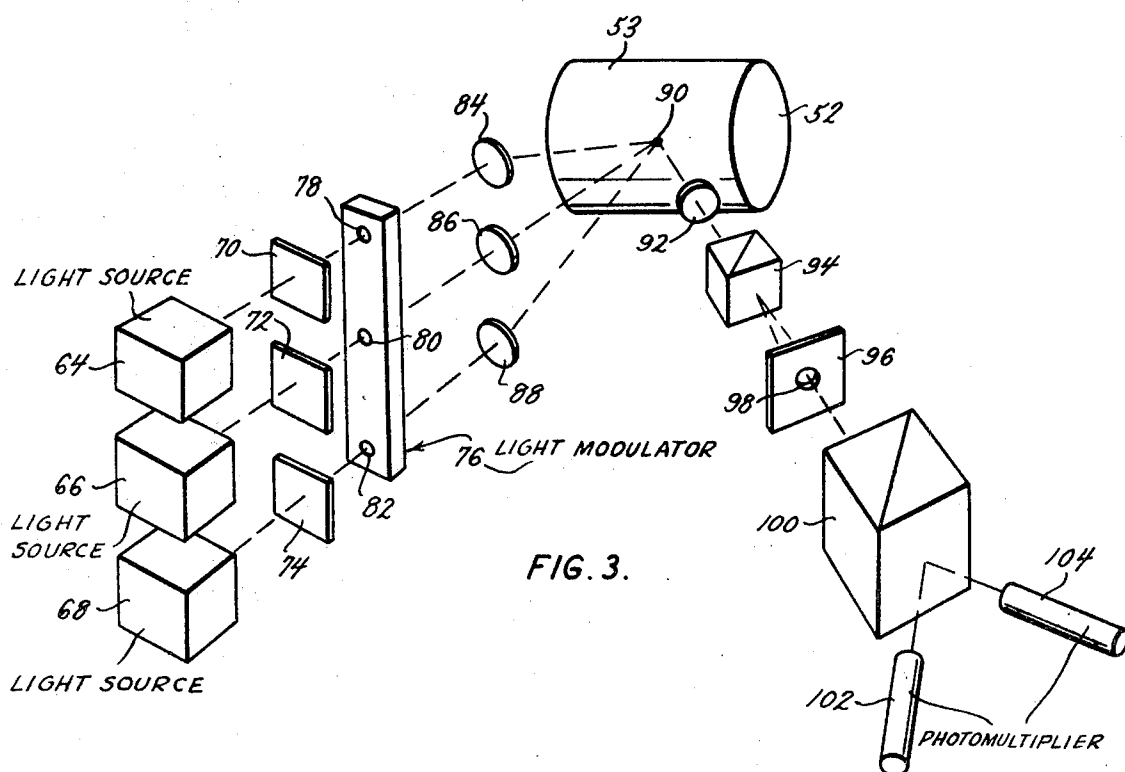


FIG. 3.

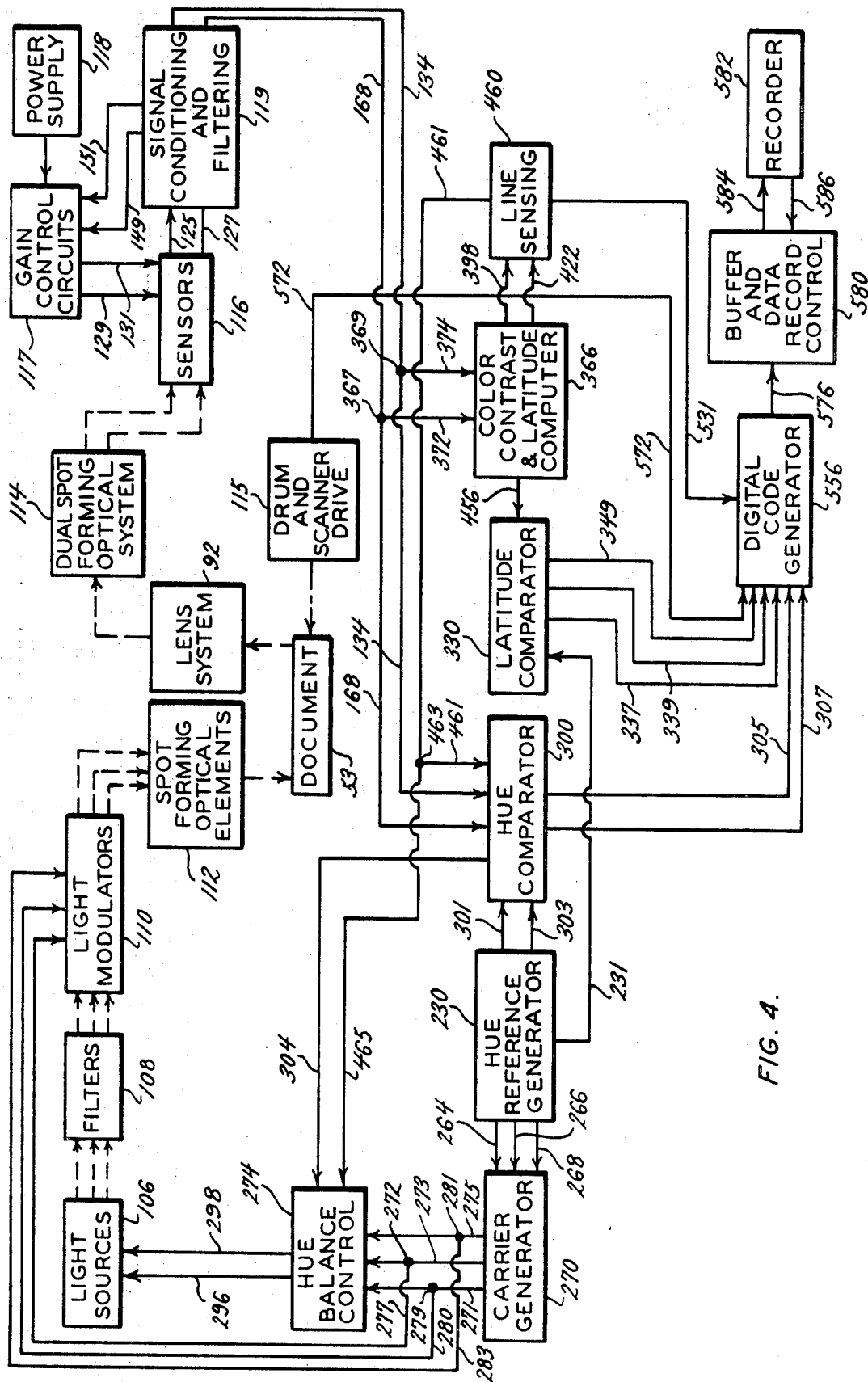


FIG. 4.

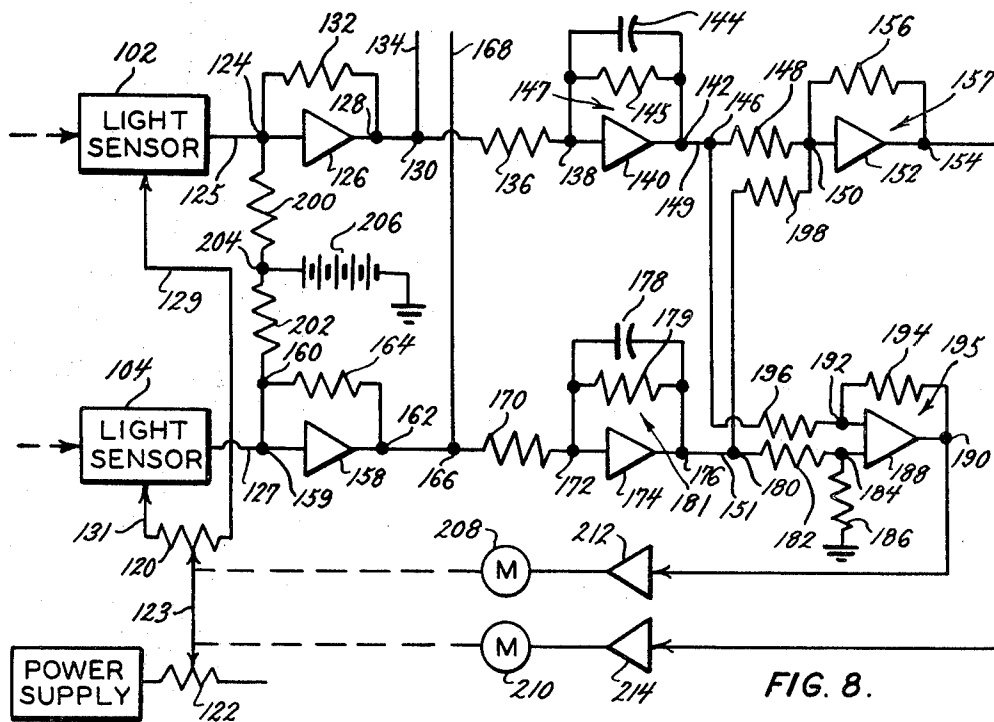


FIG. 8.

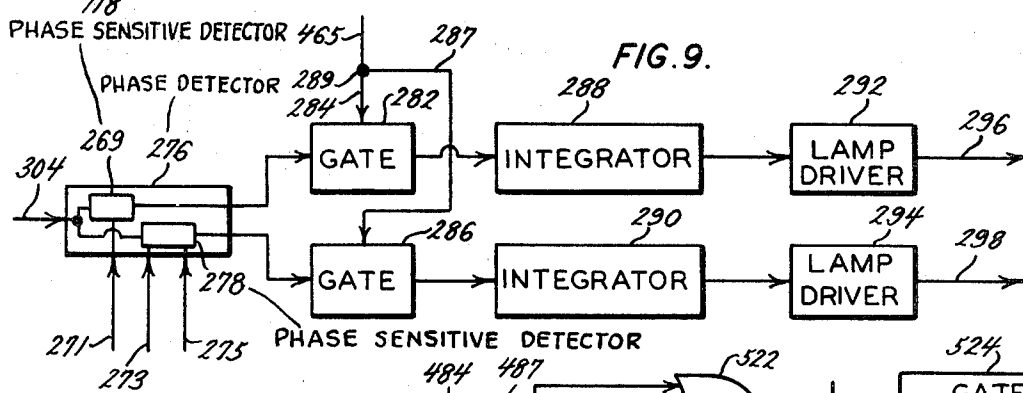


FIG. 9.

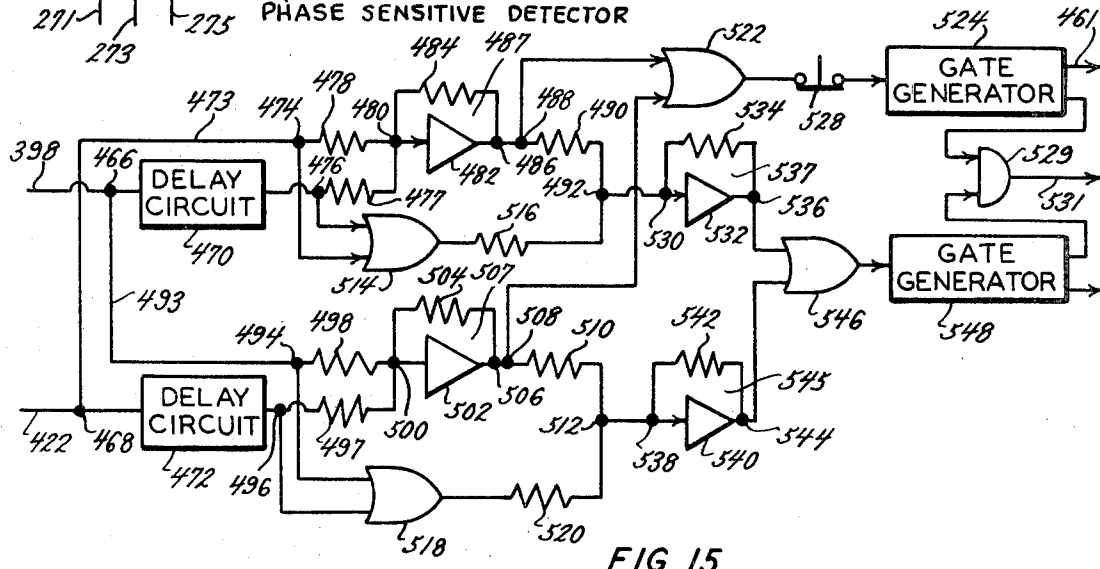
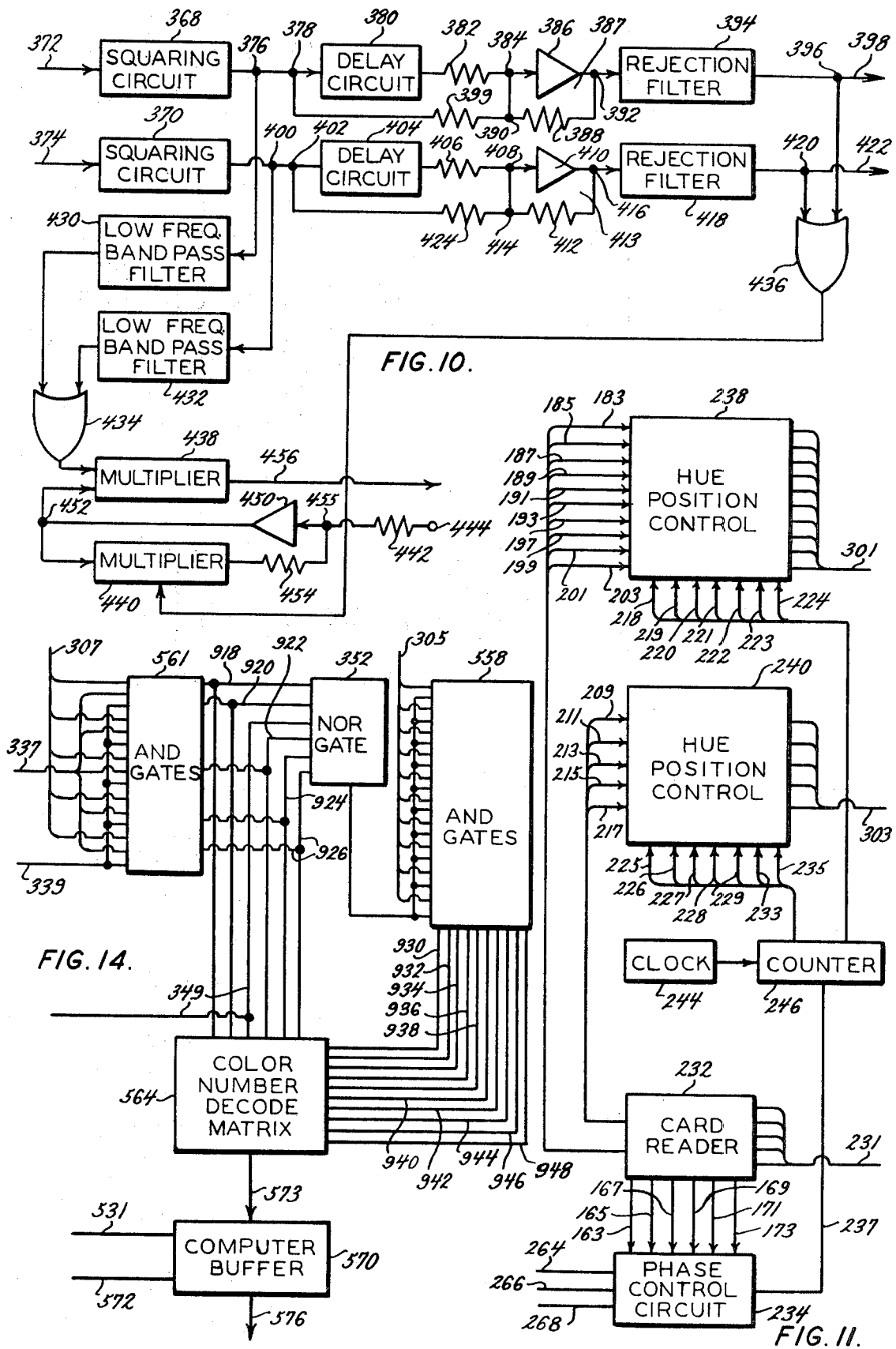
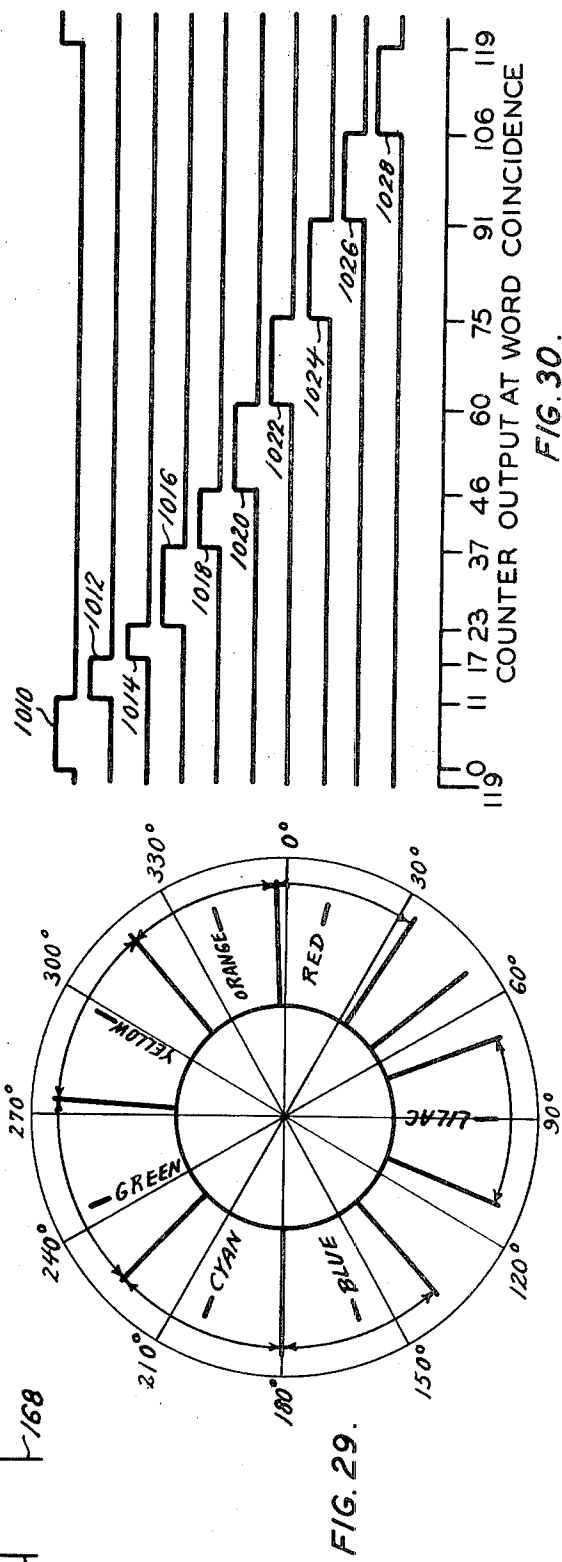
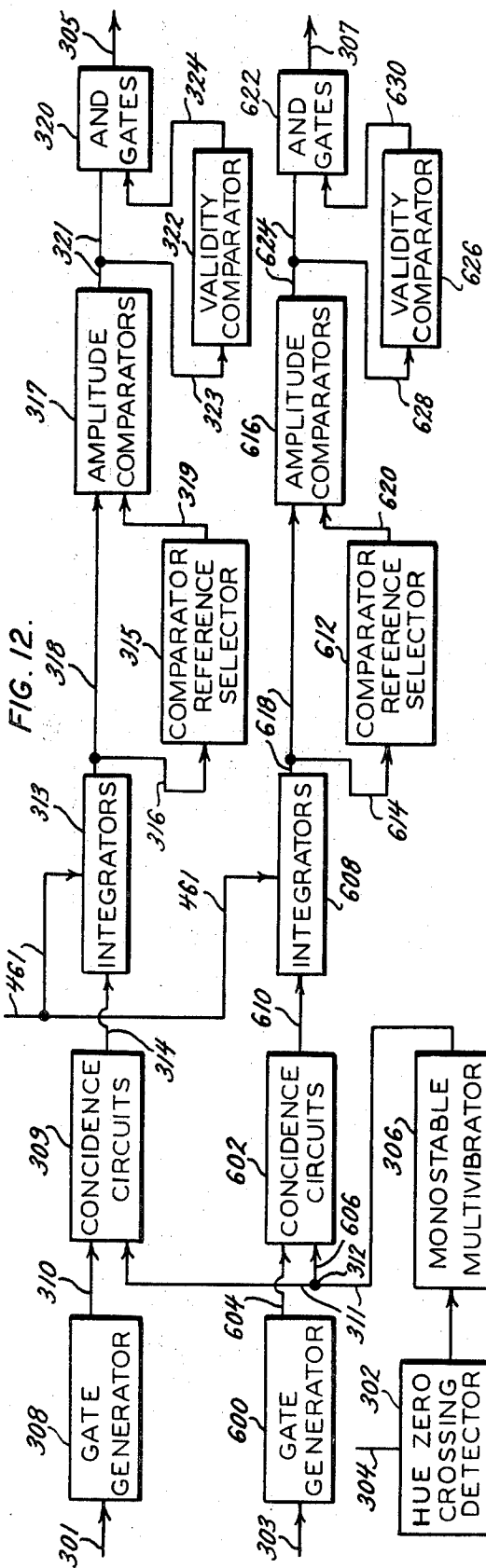


FIG. 15.





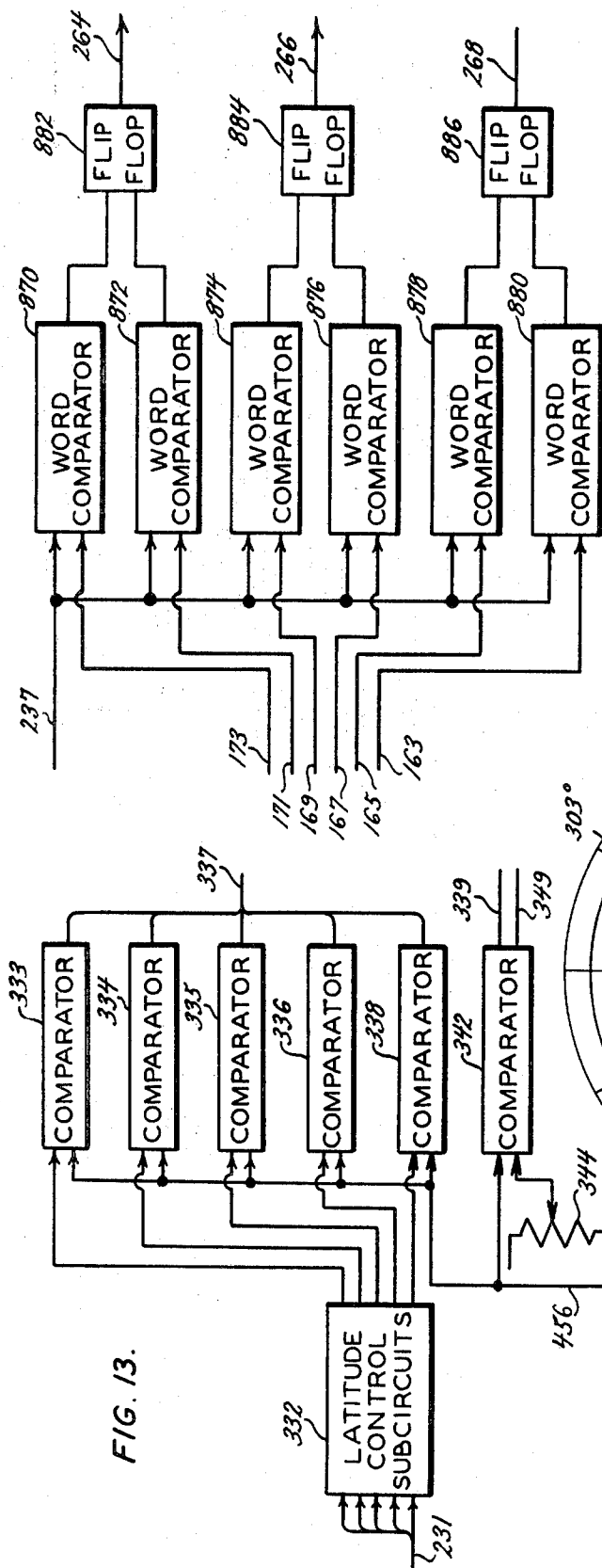


FIG. 18.

FIG. 32.

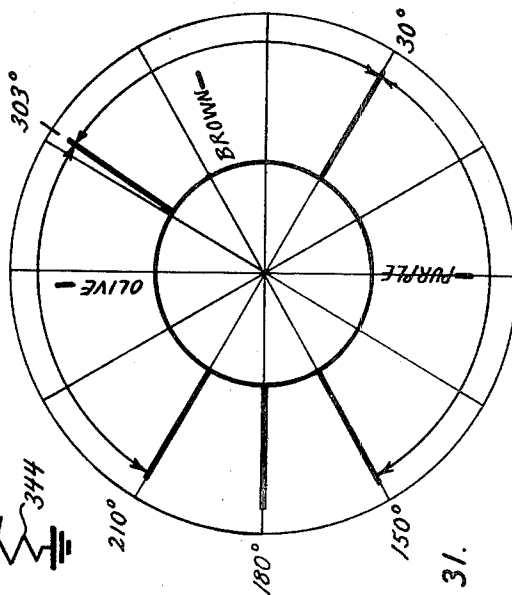
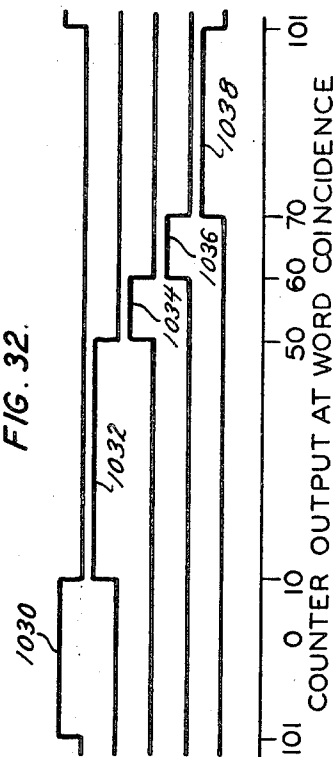
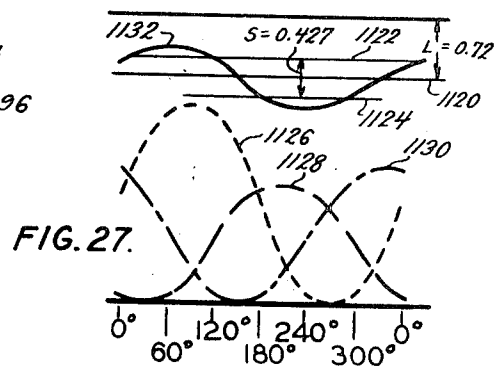
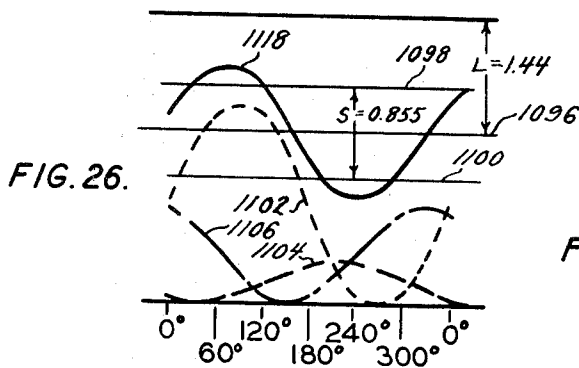
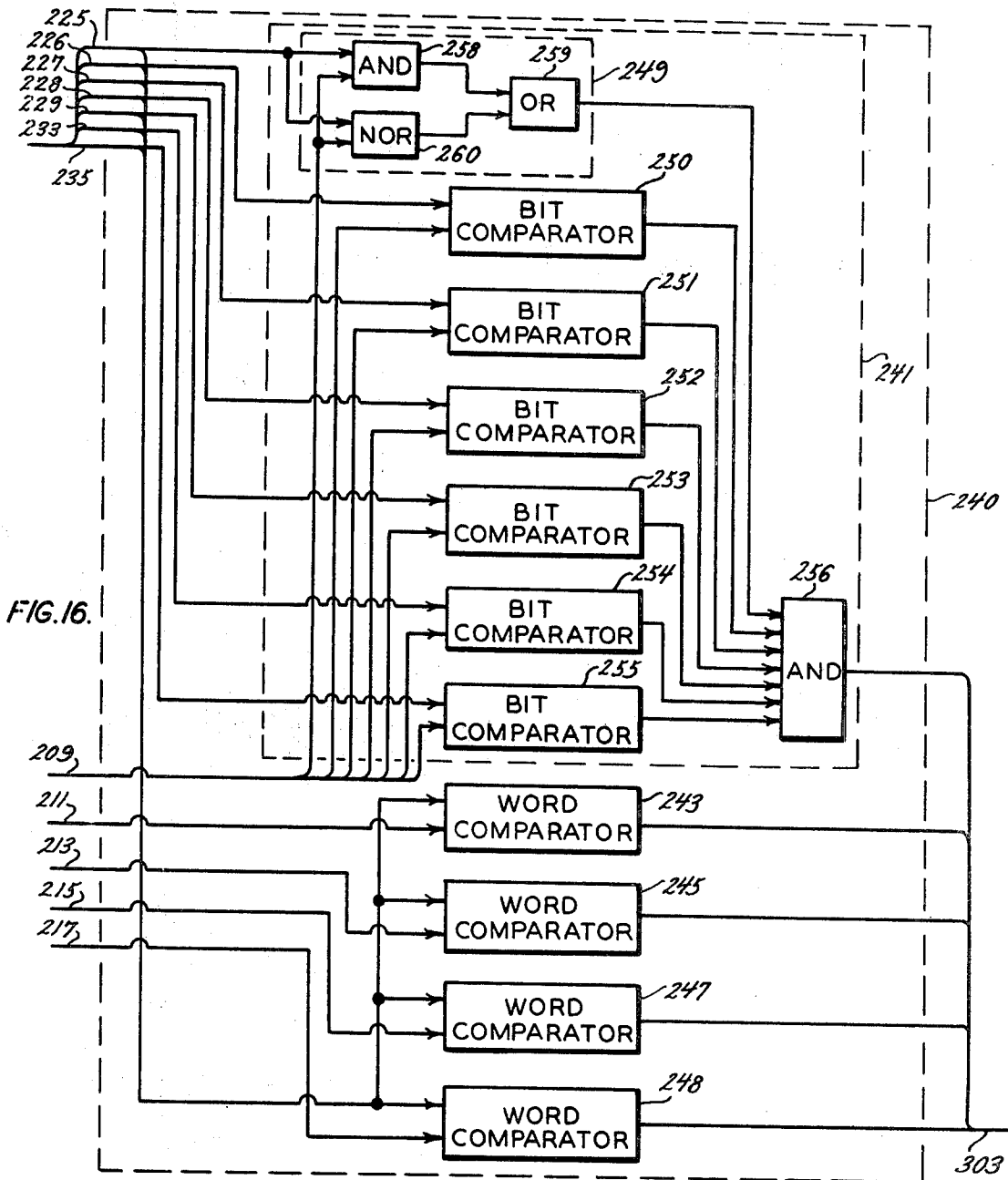
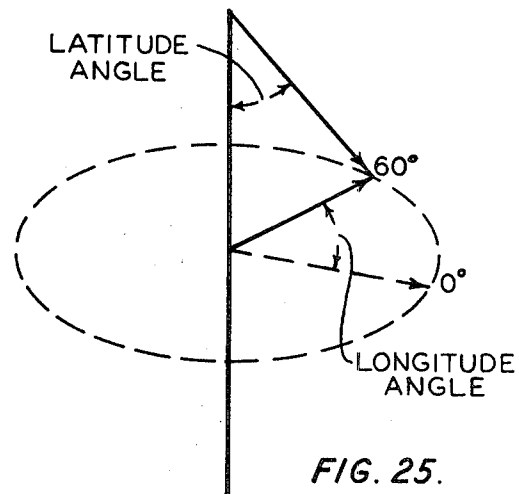
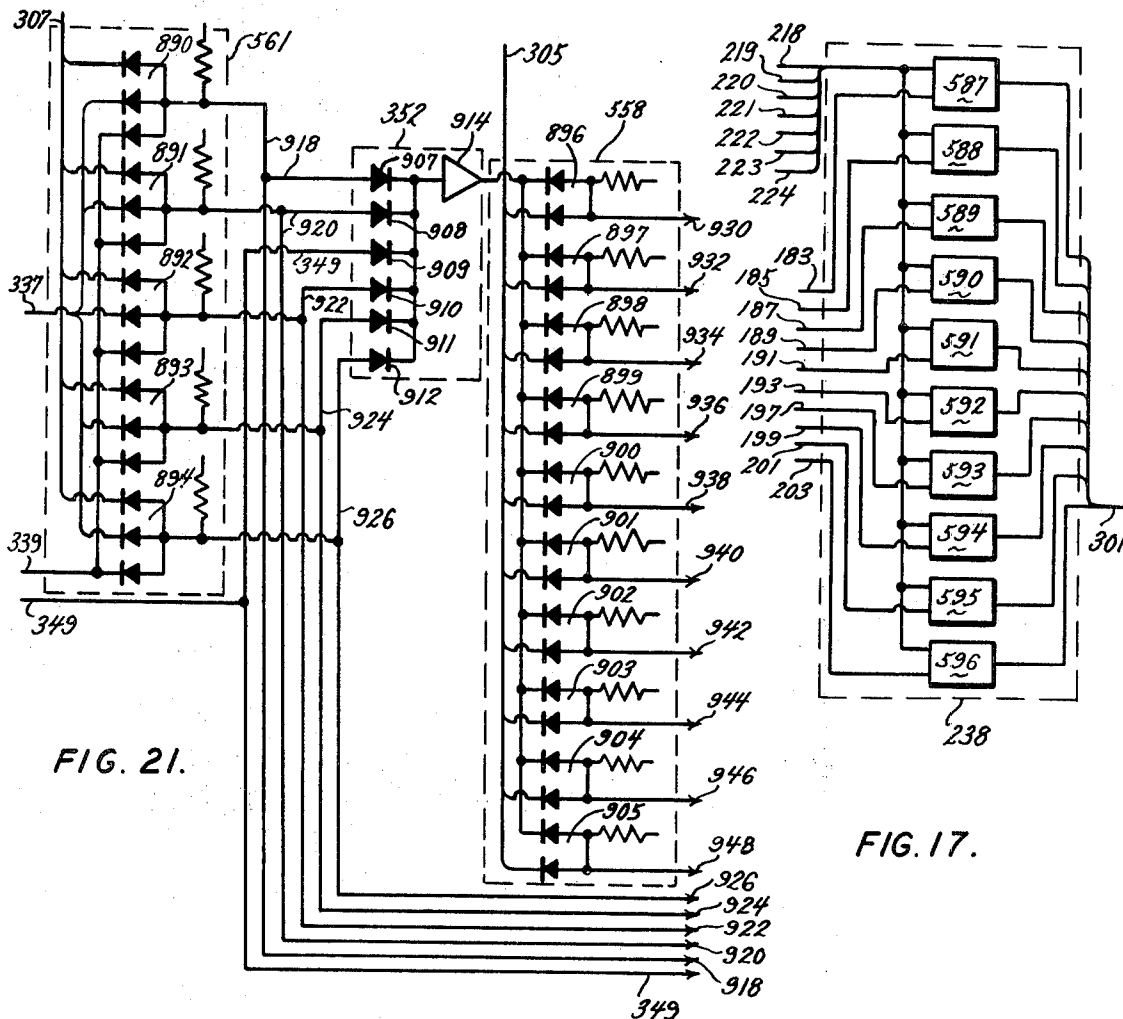


FIG. 31.





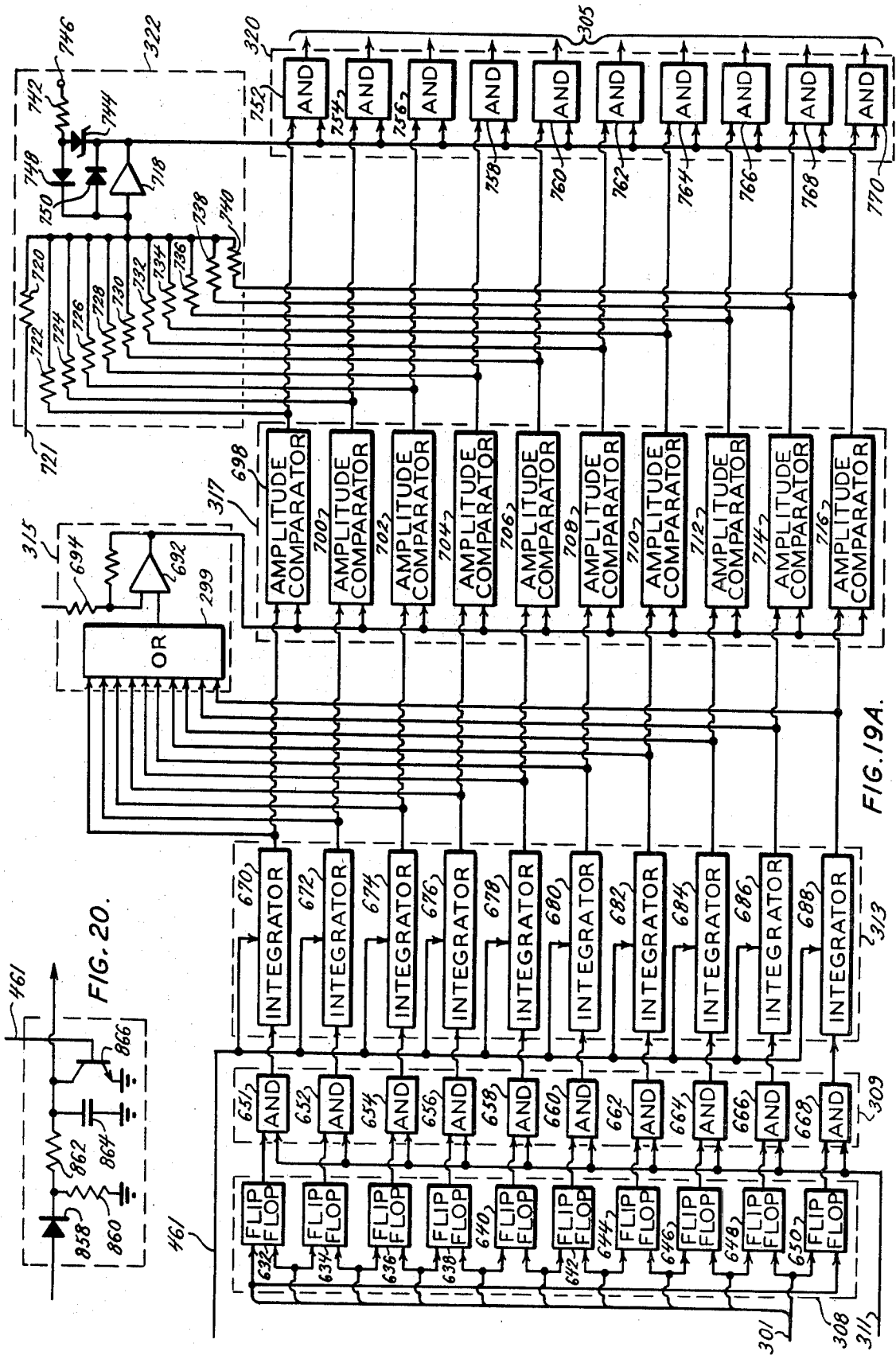


FIG. 20.

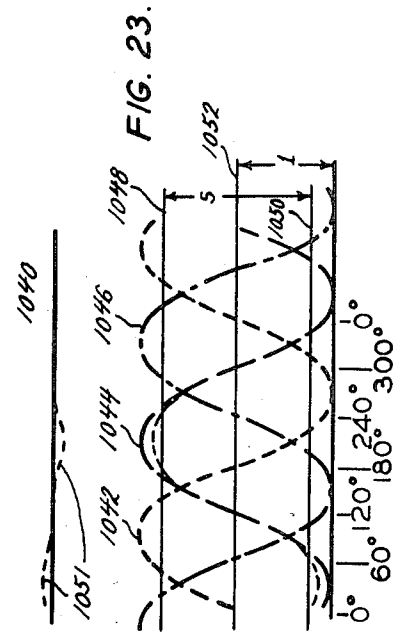
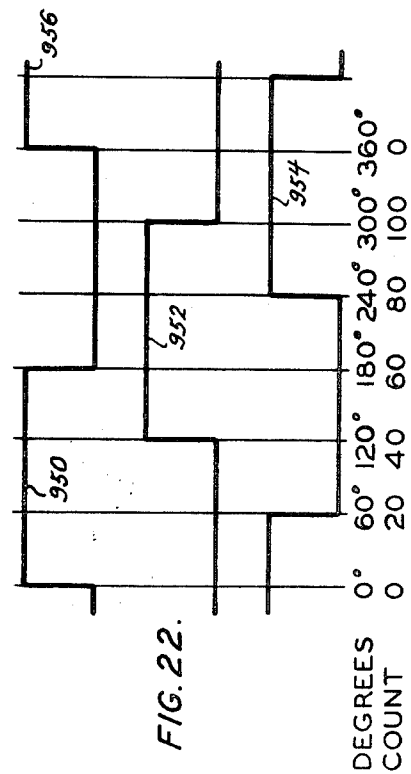
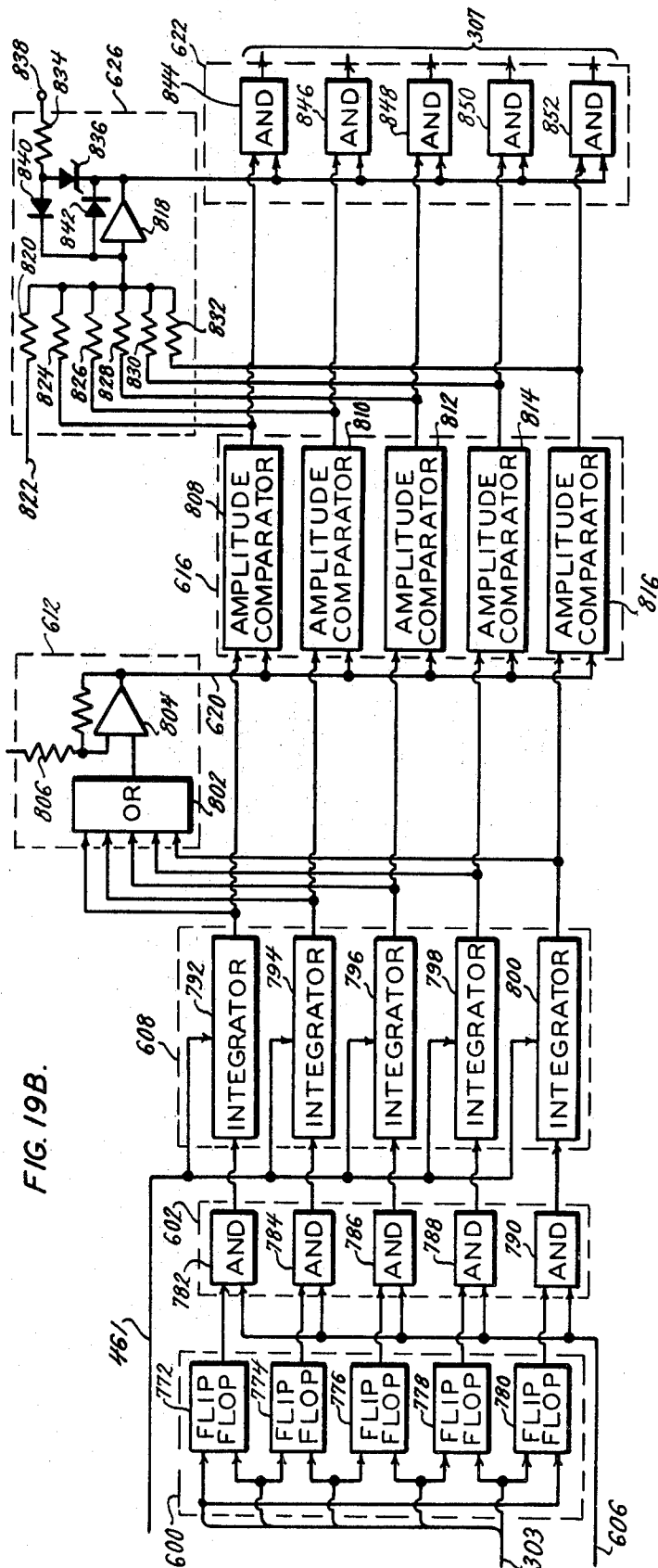


FIG. 28.

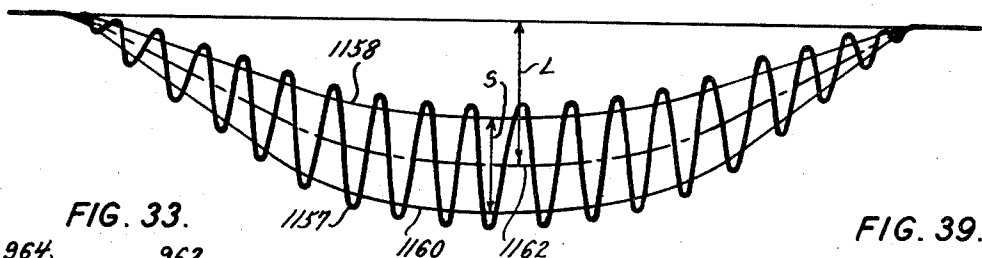


FIG. 33.

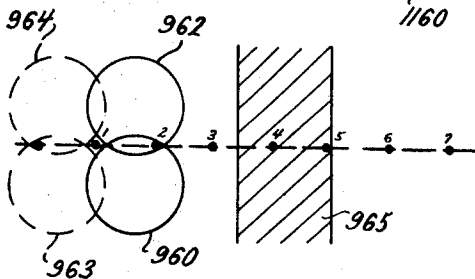


FIG. 39.

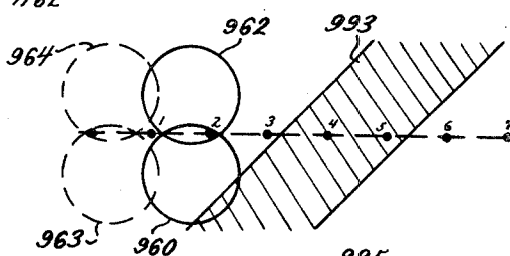


FIG. 34.

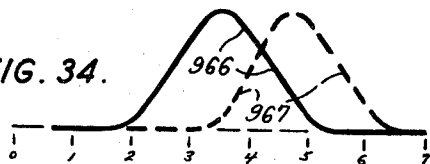


FIG. 40.

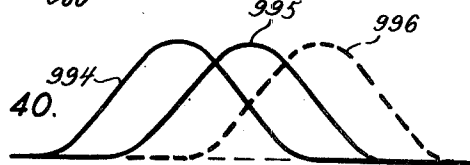


FIG. 35.

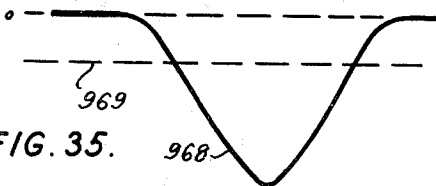


FIG. 41.

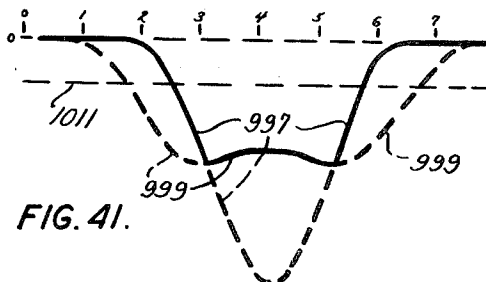


FIG. 36.

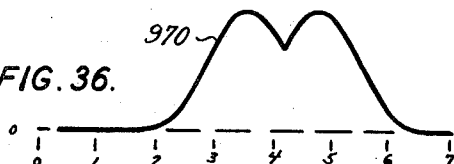


FIG. 42.

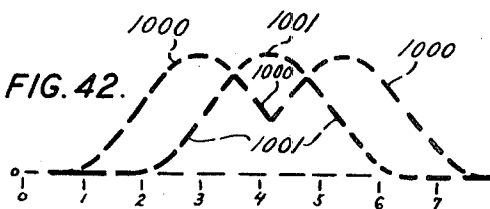


FIG. 37.

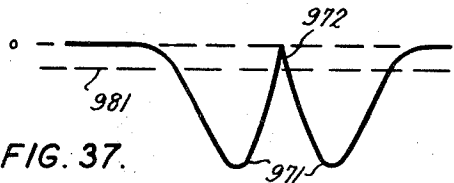


FIG. 43.

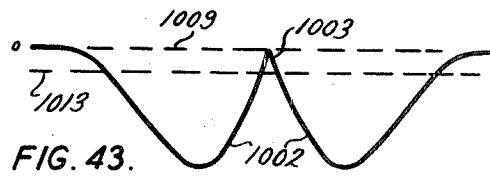


FIG. 38.

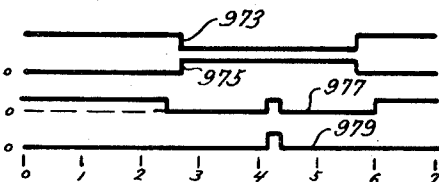


FIG. 44.

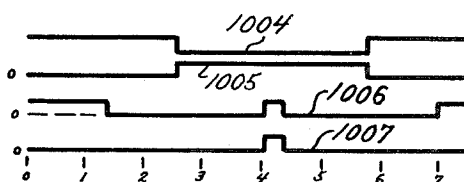


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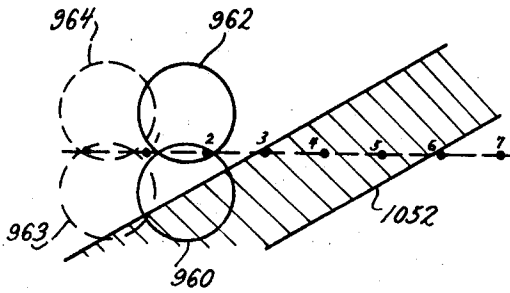


FIG. 51.

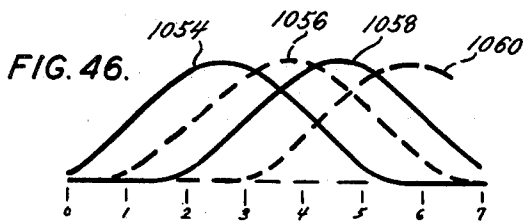
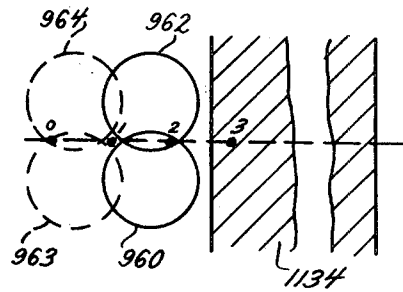


FIG. 52.

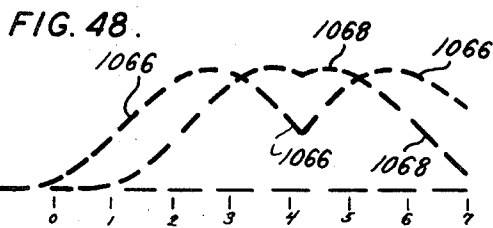
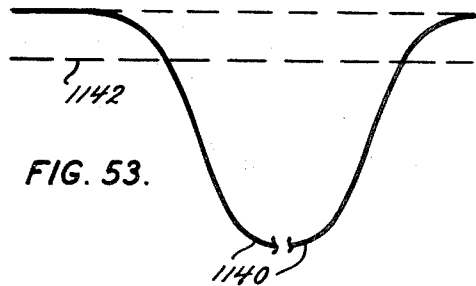
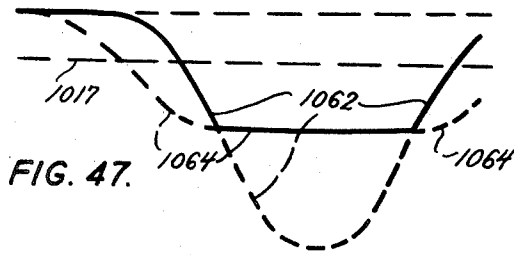
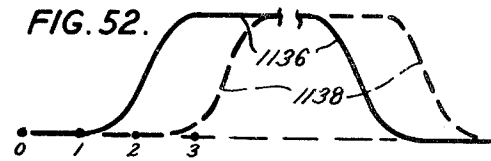


FIG. 54.

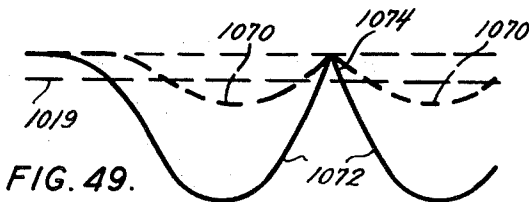
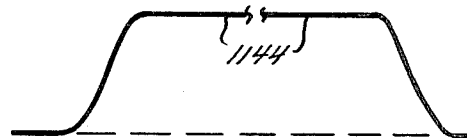


FIG. 55.

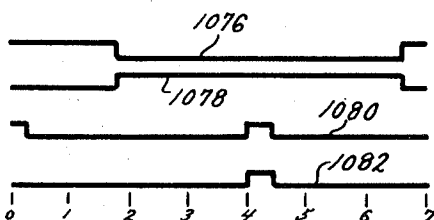
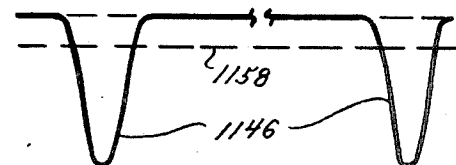


FIG. 50.

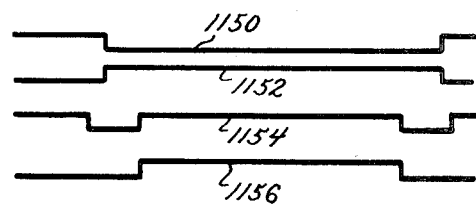


FIG. 56.

COLOR IDENTIFICATION SYSTEM TAKING INTO ACCOUNT THE COLOR AND REFLECTING OF THE BASE MATERIAL

Electro-optics systems have been devised which will scan a printed document, convert the printed data thereon to electrical signals, and transmit and/or record those electrical signals for the purpose of storage, computer manipulation, and/or reproduction of the data encoded on the printed document. Some such scanning systems have been provided with the capabilities of converting various colors on the printed document to electrical signals which could be reconverted to reproduce those colors; and those systems were intended to sense, convert, transmit, and reconvert those colors with a high degree of faithful reproduction. The colors of the colored areas on a document, such as a map, are intended to convey to the observer the fact that a particular area or line concerns a single particular parameter such as terrain contours, roads, rivers, and such; and the colors used are usually easily discriminated as being visually different, and they are chosen to avoid confusion of the parameters represented by each different color. The colors of the colored areas on a document, such as a map which is printed or drawn in color, are not homogeneous in nature; and, instead, those colors consist of incompletely pigmented areas of the paper, cloth or other base material of that document plus small volumes of pigment in the interstices of that base material. Even if the colors of the small volumes of pigment in the interstices of the base material of a given colored area on a document were of a homogeneous nature, the incompletely pigmented fibers of that base material would keep the overall color of that colored area from being homogeneous. In addition, a document, such as a map which is printed or drawn in color, may be edited by additions in colors which only approximate in appearance the original colors used on that document; and, in such cases, it is the intent to use the similar-appearing colors to convey the same meaning conveyed by the original colors. In addition, a document such as a map which is printed or drawn in color, may be edited by erasers, and this means that small traces of pigment remain, or are "smudged," into the surrounding area; and, in such cases, it would be desirable to remove those small traces of pigment by returning the pigmented area to the original color of the base material. As a result of the variations described above, the absolute colors which appear on a document, such as a map, can vary over a large range of colors although a given range of colors is intended to convey a single specific type of information. The unintended color variations appearing on the document can be considered a noise factor which is normally ignored by the visual observer. To provide an electro-optic scanning system which will perform the function of parameter identification through the use of color identification, it is desirable to identify the pigment used to print a specific color rather than to identify the absolute color resulting from that pigment. The standard color identification systems which are absolute color identification systems cannot be conveniently used to identify the pigments which define the various differently-colored areas on a printed or drawn document.

Light from a light source is passed through a filter, is passed through a light modulator, and is then passed through an optical element to form a spot of red light on the surface of a printed or drawn document, such as a map, which has differently-colored areas thereon. Light from a second light source is passed through a second filter, is passed through a second light modulator, and is then passed through a second optical element to form a spot of green light which is coincident with the spot of red light; and light from a third light source is passed through a third filter, is passed through a third light modulator, and is then passed through a third optical element to form a spot of blue light which is coincident with the spots of red and green light. The light modulators modulate the intensities of the light of the spots of red, green and blue light with a sine wave and with a phase displacement of 120° between the sine wave intensity modulation of the light of the spots of red, green and blue light; and hence, although the

combined spot of light will be essentially white, the red component of that spot of light will be dominant at a given instant, 120° later the blue component will be dominant, and 120° after that the green component will be dominant. Relative movement will be provided between the combined spot of light and the colored document to provide a scanning of the differently-colored areas on that document. During the scanning of those differently-colored areas, each scanned area will reflect light toward a lens system; and the differently-colored areas on that document will reflect light which varies in lightness, saturation and hue. That lens system will tend to image the reflected light as a spot of light on an aperture plate which has a single aperture; but an optical element which is intermediate that lens system and that aperture plate will cause two spots of light, rather than just one spot of light, to appear on that aperture plate. In addition, that optical element will orthogonally polarize the light which forms those two spots of light. The centers of those two spots of light will be displaced so individually-different portions of those two spots of light will pass through the single aperture in the aperture plate and will pass to a second optical element as a single cone of orthogonally-polarized light. That second optical element will divide that single cone of orthogonally-polarized light to form two displaced cones of light; and it will direct those displaced cones of light onto spaced-apart light-sensitive elements which will supply signals to an electronic circuit. The second optical element will additionally polarize the light, which forms the two displaced cones of light, so one of the light-sensitive elements will "see" only one of the individually-different portions of the two spots of light formed by the first optical element and so the other of those light-sensitive elements will "see" only the other of those individually-different portions of those two spots of light.

The signals which the light-sensitive elements will supply to the electronic circuit will contain lightness, saturation and hue information; and that electronic circuit will analyze that information to determine the color and reflectivity of the base material of printed or drawn colored documents, and will also analyze that information to identify the pigments in the differently-colored areas on those documents. Specifically, that electronic circuit will analyze the information from the light-sensitive elements to determine the color and reflectivity of the base material of printed or drawn colored documents, and will control the intensities of two of the light sources to keep the average value of light reflected from that base material constant. That electronic circuit also will analyze the information from the light-sensitive elements to determine the angles—which shall be referred to herein as longitude angles—which represent the differences between the hue values of the base material and of the pigments in the differently-colored areas on the document; and, in addition, that electronic circuit will combine the lightness and saturation information to develop vectors which represent the color contrasts between the base material of that document and the pigments in the differently-colored areas on that document, and it will determine the angles—which shall be referred to herein as the latitude angles—subtended by those vectors and vectors representing the differences between the lightness values of those pigments and the average lightness value of the base material of that document. Those latitude angles, those color contrast vectors, and those longitude angles will positively and accurately identify the pigments which define the various, differently-colored areas on the document—despite variations in the colors and reflectivities of different portions of the base material of that document, and despite variations in the pressures used during the printing of different portions of that document.

The optical element, which causes the two spots of light to appear on the aperture plate, is oriented relative to the direction of scanning of the document so the individually-different portions of those two spots of light, which pass through the aperture of that aperture plate, will correspond to areas on that document which are displaced transversely of that direction of scanning. The resulting, effective, transverse dis-

placement of those areas on that document is important, because it permits the simultaneous sensing of the hue angle, color contrast, and latitude angle of each of those areas. That simultaneous sensing enables the color identification system of the present invention to provide a high degree of resolution of those boundaries of the colored areas on a printed or drawn colored document which are parallel, or are only slightly inclined, to the direction of scanning. The scanning action itself enables that color identification system to provide a high degree of resolution of those boundaries of the colored areas on the document which are normal, or are sharply inclined, to the direction of scanning; and hence that color identification system is able to provide a high degree of resolution of all of the boundaries of the colored areas on a printed or drawn colored document.

This invention relates to improvements in Control Systems. More particularly, this invention relates to improvements in color identification systems.

It is, therefore, an object of the present invention to provide an improved color identification system.

Color identification systems usually are based upon the concept that each pigment has a definite position within a color solid, and that the position of each pigment can be identified by a hue angle, a saturation vector, and a lightness vector. Where the color of a material is homogeneous in nature—as in the case of an aqueous solution of a dye—an absolute color identification system can be used to accurately identify the pigment which provides the color for that material. However, the colors of colored areas on a printed or drawn colored document, such as a map, are not homogeneous in nature; and, instead, consist of incompletely-pigmented fibers of the paper, cloth or other base material of that document plus small volumes of pigment in the interstices of base material. In addition, the amount of pigment in the partially-pigmented fibers of the base material of the document will vary with variations in the ink-absorbing capability of that base material and with variations in the pressures used in printing or drawing of that document. Moreover, in a typical scanning system, a single scan line will be wide enough to sense the immediately adjacent portions of two different colored areas, and thus will provide values which are the averages of the hue values, lightness values, and saturation values of the two areas rather than the hue values, lightness values, and saturation values of either of those two areas. All of this means that the colored areas on a printed or drawn colored document do not provide a consistent absolute color value, and hence color identification systems which are based upon absolute color values are incapable of conveniently identifying the pigments used in printing or drawing. It would be desirable to provide a color identification system which could classify the colors appearing in the differently-colored areas of colored documents into groups of color ranges because such a color classification system would make it possible to automatically and accurately identify the pigments used in printing or drawing the differently-colored areas of the colored documents. The present invention provides such a color identification system; and that color identification system takes into account the color and reflectivity of the base material of each printed or drawn colored document and variations of pigmentation of the colored areas of the material, and thus is able to accurately identify the pigments used in preparing that document. It is, therefore, an object of the present invention to provide a color identification system which takes into account the color and reflectivity of the base material of a printed or drawn colored document.

The color identification system provided by the present invention identifies each pigment, used in printing or drawing a colored document, by its position within a color solid; but the position of any given pigment is not defined by the usual absolute values of hue, saturation and lightness. Instead, the position of any given pigment within the color solid is defined by an angle—referred to herein as the longitude angle—which represents the difference between the hue values of that pig-

ment and of the base material of the colored document and by an angle—referred to herein as the latitude angle—which is subtended by the lightness-difference vectors and a color contrast vector which is a function of vectors representing the difference between the lightness values and the saturation values of that base material and of that pigment. By taking into account the hue value, the lightness value, and the saturation value of the base material of the colored document, the color identification system provided by the present invention is able to accurately identify the pigments in the differently-colored areas on that document. It is, therefore, an object of the present invention to provide a color identification system which defines the position of a pigment, used in preparing a colored document, within a color solid by an angle which represents the difference between the hue values of the pigment and of the base material of the document on which that pigment is printed or drawn and by an angle which is subtended by the lightness-difference vectors and a color contrast vector which is a function of vectors representing the difference between the lightness values and the saturation values of that base material and of that pigment. It is a further object of this invention to use the color contrast vector as the criterion for detecting the presence of printed or drawn areas.

The base material of a printed or drawn colored document such as a map, usually has a substantially uniform hue value, a substantially uniform saturation value, and a substantially uniform lightness value; whereas the hue values, saturation values, and lightness values of the pigments in adjacent differently-colored areas on that document can vary widely. The color identification system provided by the present invention utilizes that fact to distinguish between the hue values, saturation values, and lightness values of the pigments of the differently-colored areas on that document; and it does so by scanning those differently-colored areas with phase-modulated light to enable light-sensitive elements to develop modulated electric signals. Those electric signals will have DC components which correspond to the hue values, saturation values, and lightness values of the base material of the colored document, and they will have AC components which correspond to the hue values, saturation values, and lightness values of the pigments in the differently-colored areas on that document. The AC components of those electric signals can be readily separated from the DC components of those electric signals; and hence the color identification system provided by the present invention can readily distinguish between the hue values, saturation values, and lightness values of the base material of a printed or drawn colored document and the hue values, saturation values, and lightness values of the pigments in the differently-colored areas on that document. It is, therefore, an object of the present invention to provide a color identification system that scans the differently-colored areas on a printed or drawn colored document with phase-modulated light to enable light-sensitive elements to develop modulated electric signals which have DC components corresponding to the hue values, saturation values, and lightness values of the base material of that document and AC components corresponding to the hue values, saturation values, and lightness values of the pigments of the differently-colored areas on that document.

In sensing the differently-colored areas on a printed or drawn colored document, it is important to precisely determine the locations of the boundaries of those differently-colored areas. Where relative movement is provided between a printed or drawn colored document and a spot of light that is used to scan the differently-colored areas on that document, and where the boundaries of the differently-colored areas are normal or are sharply inclined to the direction of scan, the time-varying signals resulting from a single scanning spot moving from one colored area into a differently-colored area can be used to determine the location of the boundary between those differently-colored areas. However, where a typical scanning system is used, and where the boundaries of the differently-colored areas are parallel or are only slightly inclined

to the direction of scan, the single scanning spot will move parallel along a boundary or move slowly from one colored area into a differently-colored area and the resulting constant signal or slowly-varying signal will not help to determine the position of the boundaries of that colored area. Moreover, in a typical scanning system, a single scan line will be wide enough to sense the immediately-adjacent portions of two differently-colored areas, and thus to provide values which are the averages of the hue values, lightness values, and saturation values of the two areas rather than the hue values, lightness values, and saturation values of either of those two areas. To enable a typical scanning system to determine the locations of boundaries which parallel or are only slightly inclined to the direction of scan, that scanning system would have to scan a line across a colored area on a document, would have to "remember" one or more of the values obtained during that scan, would have to scan a further line which did not cross that colored area, and then would have to compare the resulting one or more values with the "remembered" value or values. However, the cost of providing a scanning system with "memory" circuits is high; and, when those circuits "drift," that scanning system can not accurately locate boundaries which parallel or are only slightly inclined to the direction of scan. Consequently, it would be desirable to provide a color identification system which could simultaneously scan two areas that were displaced transversely of the direction of scan and that could develop two separate signals corresponding to those two areas. The present invention provides such a color identification system; and it is, therefore, an object of the present invention to provide a color identification system which can simultaneously sense two areas that are displaced transversely of the direction of scan and which can develop two separate signals corresponding to those two areas.

The color identification system provided by the present invention simultaneously senses two areas that are displaced transversely of the direction of scan by causing light, reflected from an illuminated spot on the surface of a printed or drawn colored document, to pass to an optical element which forms two spots of orthogonally-polarized light on an aperture plate adjacent the single aperture in that plate. Those two spots correspond to the spot of light on the printed or drawn colored document, but they have the centers thereof displaced so the portion of one of those spots which passes through that single aperture will correspond to one part of the spot of light on the colored document and so the portion of the other of those spots which passes through that single aperture will correspond to a further part of the spot of light on the colored document. A second optical element receives the light which passes through the aperture in the aperture plate; and it further polarizes that light and directs part of that light onto one light-sensitive element while directing the rest of that light onto a second light-sensitive element. The further polarization of the light will coact with the initial light polarization, provided by the first optical element, to enable the one light-sensitive element to "see" only the light reflected from the one part of the spot of light on the colored document and to enable the second light-sensitive element to "see" only the light reflected from the further part of the spot of light on the colored document. The one light-sensitive element thus will be able to develop a signal which corresponds to the light values reflected by just the one part of the spot of light on the colored document and the second light-sensitive element will be able to develop a signal which corresponds to the light values reflected by just the further part of the spot of light on the colored document. The first optical element is so oriented relative to the direction of scan that the two parts of the spot of light on the printed or drawn colored document are displaced transversely of that direction of scan. As a result, the color identification system provided by the present invention can simultaneously sense two areas on a printed or drawn colored document which are displaced transversely of the direction of scan and can develop separate signals corresponding to those two areas. It is, therefore, an object of the present

invention to provide a color identification system which has an optical element that "sees" a spot of light on a printed or drawn colored document and that forms two transversely-displaced spots of orthogonally-polarized light on an aperture plate adjacent the single aperture in that plate, and has a second optical element which further polarizes the light passing through that aperture and enables one light-sensitive element to "see" just the light corresponding to one part of the spot of light on the colored document and enables a second light-sensitive element to "see" just the light corresponding to a further part of that spot of light.

Other and further objects and advantages of the present invention should become apparent from an examination of the drawing and accompanying description.

In the drawing and accompanying description a preferred embodiment of the present invention is shown and described but it is to be understood that the drawing and accompanying description are for the purposes of illustration only and do not limit the invention and that the invention will be defined by the appended claims.

In the drawing:

FIG. 1 is a perspective view of a color solid, and it shows the location of a given pigment within that color solid;

FIG. 2 is a perspective view of a color identification unit which is intended to scan a document that has been printed or drawn in color and to develop electric signals corresponding to the differently-colored areas on that document;

FIG. 3 is a diagrammatic, perspective showing of the optical elements of the color identification unit shown in FIG. 2;

FIG. 4 is a block diagram of one preferred circuit for the color identification unit shown in FIG. 2;

FIG. 5 is a partially-sectioned, diagrammatic showing, in plan, of the manner in which a spot of light, that is reflected from a printed or drawn document, is caused to form two displaced spots of light on an aperture plate;

FIG. 6 is a diagrammatic showing, in elevation, of the two displaced spots formed on the aperture plate shown in FIGS. 3 and 5;

FIG. 7 is a showing of the waveforms of the modulated light used to form a spot of light at the surface of the printed or drawn document shown by FIGS. 2 and 3;

FIG. 8 is a block diagram which shows the components and connections of the "Sensors," "Gain Control Circuits," "Power Supply," and "Signal Conditioning and Filtering" blocks of FIG. 4;

FIG. 9 is a block diagram which shows the components and connections of the "Hue Balance Control" block of FIG. 4;

FIG. 10 is a block diagram which shows the components and connections of the "Color Contrast and Latitude Computer" block of FIG. 4;

FIG. 11 is a block diagram which shows the components and connections of the "Hue Reference Generator" block of FIG. 4;

FIG. 12 is a block diagram which shows the components and connections of the "Hue Comparator" block of FIG. 4;

FIG. 13 is a block diagram which shows the components and connections of the "Latitude Comparator" block of FIG. 4;

FIG. 14 is a block diagram which shows the components and connections of the "Digital Code Generator" block of FIG. 4;

FIG. 15 is a block diagram showing the components and connections of the "Line Sensing" block of FIG. 4;

FIG. 16 is a showing of the lower "Hue Position Control" block of FIG. 11;

FIG. 17 is a showing of the upper "Hue Position Control" block of FIG. 11;

FIG. 18 is a showing of the components and connections of the "Phase Control Circuit" block of FIG. 11;

FIG. 19A is a showing of the components and connections of the upper "Gate Generator," "Coincidence Circuits," "Integrators," "Comparator Reference Selector," "Amplitude Comparators," "Validity Comparators" and "AND Gates" blocks of FIG. 12;

FIG. 19B is a showing of the components and connections of the lower "Gate Generator," "Coincidence Circuits," "Integrators," "Comparator Reference Selector," "Amplitude Comparators," "Validity Comparators" and "AND Gates" blocks of FIG. 12;

FIG. 20 shows one form of integrator that could be used in the "Integrators" blocks of FIG. 12;

FIG. 21 is a showing of the components and connections of the "NOR Gate" block and of the two "AND Gates" blocks of FIG. 14;

FIG. 22 shows the three, phase-displaced, square waves which are developed by the "Phase Control Block" that is shown in FIG. 11 and that has the components and connections thereof shown in FIG. 18;

FIG. 23 shows the waveforms developed by the light sensors in response to light reflected from the white base material of a document;

FIG. 24 shows the waveform developed by the light sensors in response to light reflected from a colored area which absorbs all of the blue light and none of the red or green light directed onto it, and also shows the component parts of that waveform;

FIG. 25 is a perspective view of a vector diagram showing the lightness vector, the saturation vector, the contrast vector, the latitude angle, and the longitude angle of the color corresponding to the waveform of FIG. 24;

FIG. 26 shows the waveform developed by the light sensors in response to light reflected from an orange-colored area on a document, and also shows the component parts of that waveform;

FIG. 27 shows the waveform developed by the light sensors in response to light reflected from an area on a document which is white throughout one-half thereof and which is orange throughout the other half thereof, and also shows the component parts of that waveform;

FIG. 28 shows the signal developed by a light sensor as that light sensor "sees" a scanning spot of light cross an orange colored line on a document;

FIG. 29 is a polar-coordinate graph showing the longitude angles of seven representative pigments, showing seven "angle slots" incorporating those longitude angles, and showing three further "angle slots";

FIG. 30 shows waveforms corresponding to the ten "angle slots" shown in FIG. 29;

FIG. 31 is a further polar-coordinate graph showing the longitude angles of three additional representative pigments, showing three "angle slots" incorporating those longitude angles, and showing two further "angle slots";

FIG. 32 shows waveforms corresponding to the five "angle slots" shown in FIG. 31;

FIG. 33 shows an array of actual and simulated areas on a document adjacent a line on that document, and the actual areas of that array are shown by solid lines whereas the simulated areas of that array are shown by dashed lines;

FIG. 34 shows by solid and dashed lines, respectively, the waveforms developed as the line of FIG. 33 passes through the actual and simulated areas on FIG. 33;

FIG. 35 shows a waveform which represents the signals at the outputs of two of the sum amplifiers and at the output of one of the OR gates of FIG. 15;

FIG. 36 shows a waveform which represents the signals at the outputs of two of the other OR gates of FIG. 15;

FIG. 37 shows a waveform which represents the signals at the outputs of the other two sum amplifiers and at the output of the remaining OR gate of FIG. 15;

FIG. 38 shows the waveforms at the active outputs of the two gate generators and at the output of the AND gate of FIG. 15;

FIG. 39 shows the array of actual and simulated areas adjacent a further line on the document of FIG. 33;

FIG. 40 shows by solid and dashed lines, respectively, the waveforms developed as the line of FIG. 39 passes through the actual and simulated areas on FIG. 33;

FIG. 41 shows by a solid line a waveform which represents the signal at the output of one of the OR gates of FIG. 15;

FIG. 42 shows waveforms which represent the signals at the outputs of two of the other OR gates of FIG. 15;

FIG. 43 shows a waveform which represents the signals at the outputs of the other two sum amplifiers and at the output of the remaining OR gate of FIG. 15;

FIG. 44 shows the waveforms at the active outputs of the two gate generators and at the output of the AND gate of FIG. 15;

FIG. 45 shows the array of actual and simulated areas adjacent a further line on the document of FIG. 33;

FIG. 46 shows by solid and dashed lines, respectively, the waveforms developed as the line of FIG. 45 passes through the actual and simulated areas of FIG. 33;

FIG. 47 shows by a solid line a waveform which represents the signal at the output of one of the OR gates of FIG. 15;

FIG. 48 shows waveforms which represent the signals at the outputs of two of the other OR gates of FIG. 15;

FIG. 49 shows waveforms which represent the signals at the outputs of the sum amplifiers and at the output of the remaining OR gate of FIG. 15;

FIG. 50 shows the waveforms at the active outputs of the two gate generators and at the output of the AND gate of FIG. 15;

FIG. 51 shows the array of actual and simulated areas adjacent a colored area on the document of FIG. 33;

FIG. 52 shows by solid and dashed lines, respectively, the waveforms developed as the area of FIG. 51 passes through the actual and simulated areas on FIG. 33;

FIG. 53 shows a waveform which represents the signal at the output of one of the OR gates of FIG. 15;

FIG. 54 shows a waveform which represents the signals at the outputs of two of the other OR gates of FIG. 15;

FIG. 55 shows a waveform which represents the signals at the output of the other two sum amplifiers and at the output of the remaining OR gate of FIG. 15; and

FIG. 56 shows the waveforms at the active outputs of the two gate generators and at the output of the AND gate of FIG. 15.

COMPONENTS OF COLOR IDENTIFICATION UNIT

Referring to the drawing in detail, the numeral 20 generally denotes a color solid which has a diagonal 22 that is the locus of all achromatic light; and the upper end of that diagonal represents white while the lower end of that diagonal represents black. The numeral 30 denotes the position, within the color solid 20, of a given pigment; and the absolute values of the lightness, hue and saturation of that pigment determine that position. Specifically, the absolute lightness value of that pigment determines the distance 36 from the lower end of the diagonal 22 to a plane which is normal to that diagonal and which passes through the position 30. The absolute hue value of that pigment determines the angle 32 in that plane; and the absolute saturation value of that pigment determines the length of the vector 34 in that plane.

The use of absolute lightness values, absolute saturation values, and absolute hue values to identify pigments is standard in the art of colorimetry; but, while such absolute values can be used to accurately identify pigments—such as aqueous solutions of dyes—which are homogenous in nature, such absolute values can not be used to accurately identify a pigment which is printed or drawn on a colored document, such as a map. Specifically, the colored areas on a printed or drawn colored document are not areas wherein the pigments are homogeneous in nature, because those colored areas consist of incompletely-pigmented fibers of the paper, cloth or other base material of that document plus small volumes of pigment in the interstices of that base material; and hence any identification, of a pigment in a colored area on a printed or drawn document, which was based upon absolute values of lightness, saturation and hue could not accurately identify that pigment because of the lightness, saturation, and hue values of the incompletely-pigmented fibers of that base material. If normal printing or drawing pressures were used to apply a deep red

pigment to an area of a white material which had only a very limited ability to absorb that pigment, or if very light printing or drawing pressures were used to apply that pigment to an area of a white material which had an average ability to absorb that pigment, those areas would appear to be pink in color; and an identification based upon absolute values of lightness, saturation and hue would indicate—incorrectly—that the pigment was pink. The extent to which an identification based upon absolute values of lightness, saturation and hue will be in error can vary with the viscosity of the pigment, the physical softness of that pigment, the humidity at the time the document is prepared, the temperature at the time the document is prepared, the printing or drawing pressure used, the length of time the printing or drawing pressure is maintained, the ability of the base material of the map to absorb the pigment, and the lightness, saturation and hue values of that base material; and, in many cases, those errors can be gross in nature. Moreover, in a typical scanning system, a single scan line will be wide enough to sense the immediately adjacent portions of two differently-colored areas and thereby provide values which are the averages of the hue values, lightness values, and saturation values of the two areas rather than the hue values, lightness values, and saturation values of either of those two areas. Thus, as a scanning spot crosses from a white base material area into a colored area, which for purposes of illustration is deep red, the color which is sensed will vary from white through pink and red to deep red. Hence, the incompletely-pigmented fibers of the base material and the location of the scanning spot at the edge of the colored area will produce a mixture of the saturation values and the lightness values of the pigment and base material. The values of lightness, saturation, and hue of such a mixture will be average values which are dependent upon the percentage of unpigmented base material and pigmented base material which fall within the area of the scanning spot, as well as the degree of pigmentation of fibers; and those average values could be almost anywhere between the lightness, saturation, and hue values of the pigment. However, and importantly, every identification of a colored area on a printed or drawn document which is based upon absolute values of lightness, saturation and hue, will be inaccurate.

The color identification system of the present invention makes it possible to accurately identify the pigments used in printing or drawing the colored areas on a document by taking into account the effects which the incompletely-pigmented fibers of the base material of that document have upon the apparent colors of those colored areas and the effects of the scanning spot sensing immediately-adjacent portions of base material and pigmented area. Specifically, instead of merely sensing a lightness value which corresponds to the overall lightness of a colored area on a printed or drawn document, the present invention senses the lightness value of the base material of that document and then subtracts that value of lightness from all values of lightness which appear on the document, thereby developing a lightness value which accurately represents the difference between the lightness values of that base material and of the colored areas of the document. Uncolored areas will result in a lightness difference value of zero. Similarly, instead of merely sensing a saturation and hue value which corresponds to the overall hue of a colored area on a printed or drawn document, the present invention senses the saturation and hue of the base material of that document and then subtracts those values of saturation and hue from all sensed values of saturation and hue, thereby developing a saturation and hue value which accurately represents the difference between the saturation and hue values of that base material and of the colored areas on the document. Uncolored areas will result in a saturation difference value of zero, which represents an absence of hue. The color identification system of the present invention simplifies the subtracting of the lightness, saturation and hue values of the base material of a document by directing varying intensities of red, blue, and green light onto that document so an essentially constant intensity of achromatic light is detected

as being reflected from the base material of that document. Because the light detected as being reflected from that base material will be achromatic and constant in intensity, any values of hue and saturation or any changes of intensity in the light reflected from the printed or drawn colored document will be a measure of the hues and saturations and lightness of the colored areas on that document relative to any hue and saturation and lightness values of that base material.

In the color solid 20 of FIG. 1, the numeral 35 denotes the position which represents the controlled color reflected from the base material of a printed or drawn document; and the numeral 37 denotes a lightness value which corresponds to the lightness of that base material. The numeral 36 denotes a lightness vector which represents the lightness value of a pigment used in printing or drawing a colored area on that document. By subtracting the value of the lightness vector 36 from the lightness value 37, the lightness value 40 which represents the lightness difference value of that pigment can be obtained. The vector denoted by the numeral 37 is the locus of all colors which have a saturation value of zero, and hence the vector 34 will represent the difference between the saturation value of the base material and of the pigment represented by the position 30. The angle 32 which is subtended by the saturation vector 34, with respect to a reference vector 31, will represent the differences between the hue values of the base material and of the pigment represented by the position 30. A vector 38 which is drawn between the position 35 and the position 30 represents the contrast between the base material of the document and the pigment used to print or draw a colored area on that document; and the tangent of the angle 42 subtended by the vector 38 and the vector 40 represents the ratio between the saturation vector 34 and the lightness difference vector 40. In determining the pigment used in printing or drawing a colored area on a document, the color identification system provided by the present invention senses the angle 32 and the angle 42. The incompletely-pigmented fibers of the base material and the location of the scanning spot at the edge of a colored area will produce a proportional change in the vectors 40, 34, and 38; but the angles 32 and 42 will remain unchanged. The color identification system provided by the present invention senses the angles 32 and 42, thereby providing the identification of pigments independent of uncontrolled variables. The value of the contrast vector 38 also is sensed, and it is used for the purpose of detecting and determining the position of the boundaries of colored areas.

Referring particularly to FIG. 2, the numeral 50 generally denotes the cabinet of one preferred embodiment of color identification unit that is made in accordance with the principles and teachings of the present invention. That cabinet has self-aligning, preloaded ball bearing assemblies, not shown, adjacent the opposite ends thereof; and a lightweight metal drum 52 is mounted on a precision axle which is journaled in those ball bearing assemblies. That drum has an accurately-machined outer surface; and that outer surface can receive a document 53 which has been printed or drawn in color. That document can be held in intimate engagement with the outer surface of that drum by a flexible sheet of tough, transparent material, such as Mylar, which has one end thereof secured to that drum and which can have the free end thereof readily secured to or separated from that drum. The cabinet 50 also has an electric gear motor, not shown, which rotates the drum 52 at a predetermined speed; and an optical shaft encoder, not shown, which generates drum-rotation position data will be coupled to the drum 52. An adjustable servo-type mounting, not shown, will permit easy and accurate "zeroing" of that encoder relative to that drum. That encoder will preferably generate a 16-bit word for digital determination of circumferentially-spaced points on the document 53; and a count of the number of revolutions of the drum 52 will determine the spacing between axially-spaced points on that document.

The numeral 54 denotes a precision-ground guide rod which is mounted on the cabinet 50 so it is precisely parallel to the axis of rotation of the rotatable drum 52; and the numeral

56 denotes a second precision-ground guide rod which is mounted on that cabinet so it is precisely parallel to that axis of rotation. As indicated by FIG. 2, the guide rods 54 and 56 are spaced apart a short distance in the horizontal direction. A ball lead screw 58 is rotatably supported by ball bearing assemblies, not shown, which are adjacent the opposite ends of the cabinet 50; and that lead screw is precisely parallel to the axis of rotation of the rotatable drum 52 and to the guide rods 54 and 56. A precision gear train, not shown, is connected between the rotatable drum 52 and that lead screw to provide a positive and definite relationship between the rotation of that lead screw and the rotation of that rotatable drum. The numeral 60 generally denotes a scanner which has a base plate 62 that is equipped with accurately-mounted linear ball bearing assemblies, not shown. Those linear ball bearing assemblies will coact with the guide rods 54 and 56 to permit that scanner to move easily in a direction parallel to the axis of rotation of the rotatable drum 52 while effectively preventing all movement of that scanner transversely of that axis of rotation. The scanner 60 is equipped with a lead nut, not shown, which can be moved into engagement with the lead screw 58 to enable that lead screw to drive that scanner along the lengths of the guide rods 54 and 56. That lead nut can, however, be moved out of engagement with the lead screw 58 to permit the scanner 60 to be moved freely along the lengths of those guide rods. A flexible cable 61 contains flexible conductors which are connected to the electrical components mounted within the scanner 60, and that flexible cable will extend and retract as needed to permit unimpeded movement of that scanner along the lengths of the guide rods 54 and 56. The flexible conductors will extend to the electronic equipment that will be stored behind panels or doors at the front of the lower portion of that cabinet.

The cabinet 50 has a cover 63 which is shown as being transparent and which overlies and encloses the upper portion of the rotatable drum 52. That cover can be raised upwardly and moved out of register with that rotatable drum to facilitate the securing of the document 53 to, and to facilitate the separation of that document from, that rotatable drum. An elongated guard 65, which is shown as being transparent, is provided adjacent the bottom of the rotatable drum 52; and that guard will underlie and protect the bottom of that rotatable drum. The cover 63 and the guard 65 will be spaced apart sufficiently to enable the scanner 60 to directly confront the document 53.

As shown particularly by FIG. 3, the scanner 60 has three light sources 64, 66 and 68 therein; and those light sources will preferably be quartz-iodide-type incandescent lamps or zirconium arc lamps. The quartz-iodide-type incandescent lamps are desirable because they are small in size, because they have high color temperatures, and because they provide positionally-stable sources of light. Zirconium arc lamps are desirable because they are highly efficient, consume relatively low amounts of power, and provide "point" sources of light; but such lamps tend to experience objectionable instability with regard to the intensities and positions of those "point" sources of light. Each of the light sources should have a power rating of 200 or more watts.

Absorption-type filters 70, 72 and 74 are disposed, respectively, in the paths of light issuing from the light sources 64, 66 and 68; and one of those filters will essentially permit only red light to pass through it, another of those filters will essentially permit only blue light to pass through it, and the last of those filters will essentially permit only green light to pass through it. To protect the filters 70, 72 and 74 from overheating, an interference type filter, not shown, will be disposed between the light sources 64, 66 and 68 and those filters to remove energy having wavelengths longer than 700 millimicrons.

The numeral 76 generally denotes a light modulator housing which is mounted within the scanner 60; and that housing has an opening 78 in register with the light passing through the filter 70, has an opening 80 in register with the light passing through the filter 72, and has an opening 82 in register with

the light passing through the filter 74. That light modulator housing has three light modulators therein; and those light modulators are in register, respectively, with the apertures 78, 80, and 82 in that light modulator housing. Those light modulators can be opto-mechanical or opto-electrical in nature; and polarizing elements plus liquid devices such as Kerr cells, mechanical devices such as rotatable pattern-bearing discs, polarizing elements plus crystal devices such as pockel cells can be used as the light modulators in the light modulator housing 76.

The numeral 84 generally denotes an optical element which will receive the light that successively passes through the filter 70 and the aperture 78, and that optical element will form a spot of colored light on the document 53. The numeral 86 generally denotes an optical element which will receive the light that successively passes through the filter 72 and the aperture 80, and that optical element will form a spot of colored light which is congruent with the spot of colored light formed by the optical element 84; and the numeral 88 generally denotes an optical element which will receive the light that successively passes through the filter 74 and the aperture 82, and that optical element will form a spot of colored light which is congruent with the spot of colored light formed by the optical element 84 and with the spot of colored light formed by the optical element 86. The resulting spot of light is denoted by the numeral 90; and, while it will have red, blue and green components, it will be an essentially white spot of light.

The spot 90 of light illuminates the area being scanned and should be as small as alignment problems permit, in order to provide a high degree of light flux density. In the said one preferred embodiment of color identification unit, the diameter of the spot 90 is between five one-hundredths and two-tenths of an inch.

Although the optical elements 84, 86, and 88 have been shown as lenses which image the red, green, and blue light paths to a common point on the document 53, a preferred optical system would use a dichroic mirror to combine those light paths. Where the light sources 64, 66 and 68 are quartz-iodide-type incandescent lamps, the optical elements 84, 86 and 88 will preferably project demagnified images of the filaments of those light sources onto the document 53 to form the colored spots of light which combine together to form the spot 90 of light.

The light modulator in register with the aperture 78 will modulate the intensity of the light passing through that aperture; and, similarly, the light modulators in register, respectively, with the apertures 80 and 82 will modulate the intensities of the light passing through those apertures. Those light modulators will phase-displace the light of the red, green and blue spots of light, which combine together to form the spot 90 of light. The frequency of modulation, provided by the three modulators within the light modulator housing 76, must be higher than any frequency which will be developed by the relative movement between the spot 90 of light and any data printed or drawn on the document 53; and the higher the frequency of modulation of those modulators the higher the rate at which the document 53 can be scanned. The frequency of modulation of the light modulators should be as high as practical—being in the range from 100,000 cycles per second to the practical upper limit of the light modulators used and the bandwidth of the signal-processing circuits. In one preferred embodiment of color identification unit provided by the present invention, the light modulators in the modulator housing 76 will modulate the light from the light sources 64, 66 and 68 at a frequency of 200 kilocycles per second. Also, those light modulators will develop modulated waveforms which are sine waves.

The document 53 will reflect part of the light which is used to form the spot 90 of light; and a lens system 92 will tend to image that reflected light on an aperture plate 96 which has a single aperture 98 therein. The image formed on the aperture plate 96 will be an approximately 10 times magnified image of

the portion of the document 53 illuminated by the spot 90 of light. If the spot 90 of light is five one-hundredths inch in diameter at the document 53, the image of that spot at the aperture plate 96 will be five-tenths of an inch in diameter. A Wollaston prism 94 is interposed between the lens system 92 and the aperture plate 96; and that prism will receive the light from the lens system 92 and will form two spots of light on that aperture plate. Specifically, the lens system 92 will form a cone 95 of light and will direct that cone of light toward the aperture plate 96; and, but for the Wollaston prism 94, that cone of light would pass to that aperture plate, as indicated by the dash-dot lines 97 in FIG. 5. However, that prism will develop a cone of light which is indicated by the dashed lines 99 in FIG. 5 and which will form a spot 101 of light on the aperture plate 96, as shown by FIG. 6; and that prism also will develop a second cone of light which is indicated by the dotted lines 103 in FIG. 5 and which will form a spot 105 of light on that aperture plate, as shown by FIG. 6. The light in the cone 95 of light will be polarized by the Wollaston prism 94; and hence the light which forms the spot 101 of light will be polarized orthogonally relative to the light which forms the spot 105 of light.

The centers of the spots 101 and 105 of light will be displaced relative to each other and relative to the center of the aperture 98 in the aperture plate 96; and the extent to which the centers of those spots of light are displaced relative to each other can be adjusted by moving the Wollaston prism 94 closer to or farther away from that aperture plate. The diameter of each of the spots 101 and 105 should be larger than the diameter of the aperture 98 in the aperture plate 96; but the diameters of those spots should be as small as alignment problems and the range of moved positions of the Wollaston prism 94 will permit. The diameter of the aperture 98 can be equated to a spot size on the document 53 through the 10 to 1 magnification of the document image formed on the aperture plate 96. In the said one preferred embodiment of color identification unit, the diameter of the aperture 98 is fifty-thousandths to two-tenths of an inch; and such a diameter is equal to a five-thousandths to twenty-thousandths of an inch diameter at the document 53. The aperture diameter as equated to the document 53 should be larger than the transverse dimensions of the interstices in the base material of the document 53. Where that is the case, the leading and trailing edges of the small volumes of pigments in those interstices will not cause abrupt changes in the value of light reflected from that document...and thus will not cause noiselike signals to be developed by the light-sensitive elements of the color identification unit. While the leading and trailing edges of those small volumes of pigment in those interstices will be "seen" by those light sensitive elements, they will be "seen" as portions of a relatively large illuminated area and will not cause abrupt changes in the values of the light reflected from the document 53 that passes through the aperture 98...and thus will not cause noiselike signals to be developed by those light-sensitive elements.

The lens system 92 preferably constitutes a short focal length lens which has an "f number" in the range of $1\frac{1}{2}$ to 1 $\frac{8}{10}$; and one such lens is the objective lens of a microscope. Where the objective lens of a microscope is used as the lens system 92, the optical elements 84, 86 and 88 will preferably be arranged to simulate a modified microscope illuminator. In such event, the optical elements 84, 86 and 88 will provide an outer optical path through which the light that is used to form the spot 90 of light will pass to the document 53; and the lens system 92 will provide an inner optical path which is concentric with that output optical path and through which the light of the cone 95 of light will pass to the Wollaston prism 94.

The Wollaston prism 94 will inherently create some color dispersion in the spots 101 and 105 of light which it develops on the aperture plate 96; and any such color dispersion should be minimized, because it could distort the colors of the portions of those spots of light which pass through the aperture 98. The extent to which that Wollaston prism creates color

dispersion in the spots 101 and 105 of light can be sharply decreased by making that Wollaston prism from crystal quartz rather than from calcite. While a Wollaston prism which is made from crystal quartz rather than from calcite can produce only a small deviation angle, the deviation angle produced by such a Wollaston prism is large enough to produce the required displacement of the spots 101 and 105 of light relative to each other.

Portions of the light forming each of the spots 101 and 105 of light on the aperture plate 96 will pass through the aperture 98 to form a single cone of light which has orthogonally-polarized components; and a second Wollaston prism 100 will respond to that single cone of light to form a cone of light at the inlet of a light sensor 102 and to form a further cone of light at the inlet of a second light sensor 104. In the said preferred embodiment of color identification unit provided by the present invention, those light sensors are photomultiplier tubes. The second Wollaston prism 100 will further polarize the already-polarized light which passes through the aperture 98 of the aperture plate 96. That further polarization of the already-polarized light will keep the light sensor 102 from "seeing" any of the light which formed the spot 101—permitting that light sensor to "see" only the light which formed the spot 105; and that further polarization of the already-polarized light will keep the light sensor 104 from "seeing" any of the light which formed the spot 105—permitting that light sensor to "see" only the light which formed the spot 101. As a result, although both of the light sensors 102 and 104 will "see" light coming through the aperture 98, the light sensor 102 will "see" only the light which formed the left-hand portion of the spot 105 of light and the light sensor 104 will "see" only the light which formed the right-hand portion of the spot 101. The left-hand portion of the spot 105 of light corresponds to one portion of the area of the document 53 which is illuminated by the spot 90 of light, whereas the right-hand portion of the spot 101 of light corresponds to an individually-different portion of that document; and hence the light sensor 102 will effectively "see" a portion of the area of the document 53 which is individually different from the portion of the area of that document which is "seen" by the light sensor 104.

The rotation of the rotatable drum 52 will coax with the movement of the scanner 60 along the lengths of the guide rods 54 and 56 to cause the spot 90 of light to scan a helical path across the document 53. The drum 52 will preferably rotate at a rate of from 1 to 2 revolutions per second; and the scanner 60 will preferably move axially of that drum at a rate of a few thousandths of an inch during each revolution of that drum. As a result, the rate of scan will be so much greater in the circumferential direction than in the axial direction of the rotatable drum 52 that the path of scan at any instant will appear to be vertical in FIGS. 2 and 3. The portion of the area of the document 53 which is "seen" by the light sensor 102 will be disposed at one side of that path of scan, while the portion of the area of the document 53 which is "seen" by the light sensor 104 will be disposed at the opposite side of that path of scan; and this means that the light sensors 102 and 104 will simultaneously sense areas on the document at opposite sides of the path of scan. Those simultaneously-sensed areas will, in the said preferred embodiment of color identification unit, overlap so they are coextensive in part; but those simultaneously-sensed areas could, of course, be completely separate.

The spots of light which the Wollaston prism 100 forms at the inlets of the light sensors 102 and 104 will preferably be no larger than those inlets—so those light sensors will receive all of the light which is directed to them by that prism. Where that is the case, any color dispersion which would be created in those spots of light would not be hurtful; and hence the Wollaston prism 100 can be made from calcite—and thus can provide a large deviation angle.

Referring particularly to FIG. 4, the numeral 106 denotes a Light Sources block which represents the light sources 64, 66 and 68 of FIG. 3, the numeral 108 denotes a Filters block which represents the filters 70, 72 and 74 of FIG. 3, and the

numeral 110 denotes a Light Modulators block which represents the modulators within the light modulator housing 76 of FIG. 3. The numeral 112 denotes a Spot-Forming Optical Elements block which represents the optical elements 84, 86 and 88 that receive the modulated light from the light modulator housing 76 and cause that light to form the spot 90 of light at the surface of the rotatable drum 52. The numeral 114 denotes a Dual Spot-Forming Optical System block which represents the Wollaston prism 94, the aperture plate 96, and the Wollaston prism 100; and the numeral 116 denotes a Sensors block which represents the light sensors 102 and 104. The numeral 115 denotes a Drum And Scanner Drive block which represents the drive for the rotatable drum 52 and the scanner 60. As indicated by dotted lines in FIG. 4, light from the Light Sources block 106 passes to and through the filters of the Filters block 108, passes through the modulators of the Light Modulators block 110, and then passes through the optical elements of the Spot-Forming Optical Elements block 112 and strikes the document 53. As indicated by the dash-dot line in FIG. 4, the elements of the Drum And Scanner Drive block 115 will rotate the document 53 relative to the light directed toward that document by the optical elements of the Spot-Forming Optical Elements block 112. As indicated by further dotted lines in FIG. 4, the light reflected from that document will pass through the lens system 92 and then through the elements of the Dual Spot Forming Optical System block 114 to the light sensors 102 and 104 of the Sensors block 116.

The numeral 117 in FIG. 4 generally denotes a Gain Control Circuits block; and the numeral 118 denotes a Power Supply block which supplies power to that Gain Control Circuits block. The Gain Control Circuits block 117, in turn, supplies power to the Sensors block 116 by conductors 129 and 131. The numeral 119 denotes a Signal Conditioning And Filtering block; and that block receives signals from the Sensors block 116 by conductors 125 and 127. The block 119 applies part of the output thereof to the Gain Control Circuits block 117 by conductors 149 and 151; and it supplies the rest of the output thereof to other blocks in FIG. 4 by conductors 134 and 168. The components and connections of the Gain Control Circuits block 117 and of the Signal Conditioning And Filtering block 119 are shown in FIG. 8.

The numeral 230 in FIG. 4 denotes a Hue Reference Generator block, and the components and connections of that block are shown in FIG. 11. The numeral 270 denotes a Carrier Generator block, and that block contains wave-shaping networks which convert square waves into sine waves. Three conductors 264, 266 and 268 extend from the Hue Reference Generator block 230 to the Carrier Generator block 270, as shown by FIG. 4.

The number 274 denotes a Hue Balance Control block, and the components and connections of that block are shown in FIG. 9. Conductors 271, 273 and 275 extend from the Carrier Generator block 270 to the Hue Balance Control block 274; and a junction 272 and a conductor 277 connect conductor 273 to the Light Modulators block 110, a junction 279 and a conductor 280 connect conductor 271 to that block, and a junction 281 and a conductor 283 connect conductor 275 to that block. The Hue Balance Control block 274 is connected to the Light Sources block 106 by conductors 296 and 298.

The numeral 300 denotes a Hue Comparator block, and the components and connections of that block are shown in FIG. 12. The numeral 301 denotes a cable which includes 10 conductors and which extends from the Hue Reference Generator block 230 to the Hue Comparator block 300; and the numeral 303 denotes a cable which includes five conductors and which extends from the former block to the latter block. The conductors 134 and 168 extend from the Signal Conditioning And Filtering block 119 to the Hue Comparator block 300; and a conductor 304 extends from the latter block to the Hue Balance Control block 274.

The numeral 330 denotes a Latitude Comparator block, and the components and connections of that block are shown in FIG. 13. The numeral 231 denotes a cable which includes

five conductors and which extends from the Hue Reference Generator block 230 to the Latitude Comparator block 330.

The numeral 366 denotes a Color Contrast And Latitude Computer block, and the components and connections of that block are shown in FIG. 10. A junction 367 and a conductor 372 connect the conductor 168 to the Color Contrast And Latitude Computer block 366; and a junction 369 and a conductor 374 connect the conductor 134 to that block. A conductor 456 extends from the Color Contrast And Latitude Computer block 366 to the Latitude Comparator block 330.

The numeral 460 denotes a Line Sensing block, and the components and connections of that block are shown in FIG. 15. Conductors 398 and 422 extend from the Color Contrast And Latitude Computer block 366 to the Line Sensing block 460. A conductor 461 extends from the Line Sensing block 460 to the Hue Comparator block 300; and a junction 463 and a conductor 465 connect that conductor to the Hue Balance Control block 274.

The numeral 556 denotes a Digital Code Generator block, and the components and connections of that block are shown in FIG. 14. A conductor 531 extends from the Line Sensing block 460 to the Digital Code Generator block 556; and a conductor 572 extends from the Drum And Scanner Drive block 115 to the Digital Code Generator block. The numeral 305 denotes a cable which includes 10 conductors and which extends from the Hue Comparator block 300 to the Digital Code Generator block 556; and the numeral 307 denotes a cable which includes five conductors and which extends from the former block to the latter block. The numeral 337 denotes a cable which includes five conductors and which extends from the former block to the latter block. The numeral 337 denotes a cable which includes five conductors and which extends from the Latitude Comparator block 330 to the Digital Code Generator block 556; and numerals 339 and 349 denote two conductors which extend from the former block to the latter block.

The number 580 denotes a Buffer And Data Record Control block; and a conductor 576 extends between the Digital Code Generator block 556 and the Buffer And Data Record Control block. The numeral 582 denotes a Recorder block; and a conductor 584 extends between the Buffer And Data Record Control block 580 and that Recorder block, while a conductor 586 extends between that Recorder block and the Buffer And Data Record Control block.

Referring particularly to FIG. 8, which shows the components and connections of the Gain Control Circuits block 117 and of the Signal Conditioning And Filtering block 119 of FIG. 4, the numeral 120 denotes a potentiometer which has one end thereof connected to the light sensor 102 by the conductor 129, and which has the other end thereof connected to the light sensor 104 by the conductor 131. The numeral 122 denotes a potentiometer which has one end thereof connected to the power supply 118—shown in FIG. 4 as well as in FIG. 8—and that potentiometer is used as an adjustable resistor. The movable contacts of the potentiometers 120 and 122 are connected together by a conductor 123.

The output of the light sensor 102 is connected to the input of a wide band amplifier 126 by the conductor 125 and a junction 124; and that junction and a junction 128 connect a resistor 132 between the output and input of that amplifier. The numeral 206 denotes a source of positive reference voltage; and, while that positive reference source is shown as a battery, it could be a regulated source of DC. A junction 204, a resistor 200, and the junction 124 connect that positive reference source to the input of the amplifier 126. The junction 128 and a junction 130 connect the output of the amplifier 126 to the conductor 134 which extends into FIG. 12 and which is connected to FIG. 10 by the junction 369 and the conductor 374. The junctions 128 and 130, a resistor 136, and a junction 138 connect the output of the amplifier 126 to the input of an operational amplifier which is generally denoted by the numeral 147. That operational amplifier includes an amplifier 140 and a parallel-connected capacitor 144 and resistor 145

which are connected between the output and input of the amplifier 140 by a junction 142 and the junction 138. That operational amplifier functions as a low pass filter; and, in the said preferred embodiment of light identification unit provided by the present invention, passes only DC signals and signals having frequencies below 1 kilocycle per second. A junction 146, a resistor 148, and a junction 150 connect the output of the operational amplifier 147 to the input of a sum amplifier which is generally denoted by the numeral 157, and which includes an amplifier 152 that has a junction 156 connected between the output and input thereof by a junction 154 and the junction 150.

The numeral 158 denotes a wide band amplifier which has the input thereof connected to the output of the light sensor 104 by the conductor 127 and a junction 159; and a resistor 164 is connected between the input and the output of that amplifier by a junction 162, a junction 160, and the junction 159. The positive reference source 206 is connected to the input of the amplifier 158 by the junction 204, a resistor 202, and the junctions 160 and 159. The junction 162 and a junction 166 connect the output of the amplifier 158 to the conductor 168 which extends into FIG. 12 and which is connected to FIG. 10 by the junction 367 and the conductor 372. The junctions 162 and 166, a resistor 170, and a junction 172 connect the output of the amplifier 158 to the input of an operational amplifier which is generally denoted by the numeral 181; and that operational amplifier includes an amplifier 174 and a parallel-connected capacitor 178 and resistor 179 which are connected between the output and input of the amplifier 174 by a junction 176 and the junction 172. That operational amplifier functions as a low pass filter; and, in the said preferred embodiment of light identification unit provided by the present invention, passes only DC signals and signals having frequencies below 1 kilocycle per second. A junction 180, a resistor 182, and a junction 184 connect the output of the operational amplifier 181 to the lower input of a difference amplifier which is generally denoted by the numeral 195; and that difference amplifier includes a differential amplifier 188 that has a resistor 194 connected between the output and the upper input thereof by junction 190 and 192. A resistor 186 is connected between the junction 184 and ground, and thus displaces the lower input of the differential amplifier 188 from ground. A resistor 196 connects the output of the operational amplifier 147 to the upper input of the difference amplifier 195; and a resistor 198 connects the output of the operational amplifier 181 to the input of the sum amplifier 157.

The numeral 208 denotes a servomotor which is mechanically connected to the movable contact of the potentiometer 120, and which can be energized to shift that movable contact in either direction. The numeral 210 denotes a similar servomotor which is mechanically connected to the movable contact of the potentiometer 122, and which can be energized to shift that movable contact in either direction. The numeral 212 denotes a driver amplifier which is connected to the output of the difference amplifier 195; and the output of that driver amplifier is connected to the servomotor 208. The numeral 214 denotes a driver amplifier which is connected to the output of the sum amplifier 157; and the output of that driver amplifier is connected to the servomotor 210.

The resistors 148, 182, 186, 196 and 198, the sum amplifier 157, the difference amplifier 195, the potentiometers 120 and 122, the driver amplifiers 212 and 214, and the servomotors 208 and 210 are the components of the Gain Control Circuits block 117 of FIG. 4. The reference voltage source 206, the resistors 132, 136, 164, 170, 200 and 202, the amplifiers 126 and 158, and the operational amplifiers 147 and 181 are the components of the Signal Conditioning And Filtering Circuits block 119 of FIG. 4. Although the blocks 117 and 119 are shown as separate blocks, the components of those blocks coact to form a loop which adjusts the gains of the light sensors 102 and 104 to provide a constant total sensitivity that will compensate for slow variations in the reflectance coefficient of the base material of the document 53, for slow varia-

tions in the intensities of the light sources 64, 66 and 68, and for slow variations in the gains of those light sensors. The components of those two blocks also coact to form a loop which balances the gains of those light sensors.

Referring particularly to FIG. 9, which shows in block form the components and connections of the Hue Balance Control block which is connected to the output of the Carrier Generator block 270 of FIG. 4 by the conductors 271, 273 and 275. That Phase Detector block also is connected to the Hue Comparator block 300 of FIG. 4 by the conductor 304. The numeral 282 denotes a gate—in the form of an on-off electronic switch—that has one of the inputs thereof directly connected to one of the outputs of the phase detector 276, and which has a second input 284. The numeral 286 denotes a second gate—in the form of an on-off electronic switch—that has one of the inputs thereof directly connected to the other output of the phase detector 276, and which has a second input 287. The inputs 284 and 287 of the gates 282 and 286 are connected together by the junction 289 and to the Line Sensing block 460 shown in FIG. 4 by the junction 289, conductor 465, junction 463 and conductor 461. An integrator 288 has the input thereof directly connected to the output of the gate 282, and it has the output thereof directly connected to the input of a lamp driver 292. The output of that lamp driver is connected to the Light Sources block 106 in FIG. 4 by conductor 296, and it will supply power to the light source 64. The output of the gate 286 is directly connected to the input of an integrator 290, and the output of that integrator is directly connected to the input of a lamp driver 294. The output of that lamp driver is connected to the Light Sources block 106 in FIG. 4, by conductor 298, and it will supply power to the light source 66. The light source 68 will have power supplied to it by a suitable source of adjustable DC power, not shown.

Referring particularly to FIG. 11, which shows in block form the components and connections of the Hue Reference Generator block 230 of FIG. 4, the numeral 232 denotes a card reader of standard and usual design; and that card reader has five outputs which are connected to the five conductors of cable 231—which extends to the Latitude Comparator block 330 in FIG. 4. That card reader has six outputs which are directly connected to six inputs of a Phase Control Circuit block 234 by six cables 163, 165, 167, 171 and 173; and each of those cables includes seven conductors. Each of those six outputs of the card reader will continuously supply a fixed 7-bit word to that Phase Control Circuit block; and those 7-bit words will be individually different. The card reader 232 has 10 outputs which are connected to 10 inputs of a Hue Position Control block 238 by 10 cables 183, 185, 187, 189, 191, 193, 197, 199, 201 and 203; and each of those cables includes seven conductors. Each of those 10 outputs of the card reader will continuously supply a fixed 7-bit word to that Hue Position Control block; and those 7-bit words will be individually different. The card reader 232 has five outputs which are connected to five inputs of a Hue Position Control block 240 by five cables 209, 211, 213, 215 and 217; and each of those cables includes seven conductors. Each of those five outputs of the card reader will continuously supply a fixed 7-bit word to the Hue Position Control block 240; and those 7-bit words will be individually different.

The numeral 244 denotes a crystal-controlled clock which generates pulses at a frequency of 24 megacycles per second. The numeral 246 denotes a counter which includes seven flip-flop circuits; and that counter is connected to the clock 244 and receives 24 megacycles per second pulses from that clock. That counter generates a 7-bit word wherein the bits continually change at the rate of 24 megacycles per second; and, in addition, that counter counts to 120 and then automatically resets itself—providing a frequency of 200 kilocycles per second as it does so. The counter 246 supplies that 7-bit word to the Hue Position Control block 238 by seven conductors 218, 219, 220, 221, 222, 223 and 224; and it supplies that 7-bit word to the Hue Position Control block 240 by seven con-

ductors 225, 226, 227, 228, 229, 233 and 235. The counter 246 also supplies that 7-bit word to the Phase Control Circuit block 234 by a cable 237 which has seven conductors. The Phase Control Circuit block is connected to the Carrier Generator block 270 by the conductors 264, 266, and 268. The Hue Position Control block 238 has 10 outputs which are connected to 10 inputs of the Hue Comparator block 300 by the 10 conductors of cable 301. The Hue Position Control block 240 has five outputs which are connected to five inputs of the Hue Comparator block 300 by the five conductors of cable 303.

The components and connections of the Hue Position Control block 240 of FIG. 11 are shown in block form in FIG. 16; and that Hue Position Control block includes five Word Comparators 241, 243, 245, 247 and 248. Each of those Word Comparators has 7-Bit Comparators and an AND gate. The Bit Comparators of the Word Comparator 241 are denoted by the numerals 249, 250, 251, 252, 253, 254 and 255, and the AND gate of that Word Comparator is denoted by the numeral 256. Each Bit Comparator of each Word Comparator of the Hue Position Control block 240 has an AND, gate, and OR gate, and a NOR gate; and the numeral 258 denotes the AND gate of Bit Comparator 249, the numeral 259 denotes the OR gate of that Bit Comparator, and the numeral 260 denotes the NOR gate of that Bit Comparator.

The cable 209 which extends from the card reader 232 to the Hue Position Control block 240 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 241, the cable 211 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 243, the cable 213 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 245, the cable 215 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 247, and the cable 217 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 248. The seven conductors 225, 226, 227, 228, 229, 233 and 235 which extend from the counter 246 to the Hue Position Control block 240 are connected, respectively, to the upper inputs of the AND gates and NOR gates of each Bit Comparator of each Word Comparator 241, 243, 245, 247 and 248.

The components and connections of the Hue Position Control block 238 of FIG. 11 are shown in block form in FIG. 17; and that Hue Position Control block includes 10 Word Comparators 587, 588, 589, 590, 591, 592, 593, 594, 595 and 596. Each of those Word Comparators has 7-Bit Comparators and an AND gate—as do the Word Comparators of the Hue Position Control block 240. Moreover, each Bit Comparator of each Word Comparator of the Hue Position Control block 238 has an AND gate, an OR gate, and a NOR gate—as do the Bit Comparators of the Hue Position Control block 240.

The cable 183 which extends from the card reader 232 to the Hue Position Control block 238 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 587, the cable 185 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 588, the cable 187 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 589, the cable 189 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 590, the cable 191 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 591, the cable 193 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 592, the cable 197 has the

seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 593, the cable 199 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 594, the cable 201 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 595, and the cable 203 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 596. The seven conductors 218, 219, 220, 221, 222, 223 and 224 which extend from the counter 246 to the Hue Position Control block 238 are connected, respectively, to the upper inputs of the AND gates and NOR gates of each Bit Comparator of each Word Comparator 587, 588, 589, 590, 591, 592, 593, 594, 595 and 596.

The components and connections of the Phase Control Circuit block 234 of FIG. 11 are shown in block form in FIG. 18; and that Phase Control Circuit block has six Word Comparators 870, 872, 874, 876, 878 and 880. Each of those Word Comparators has seven Bit Comparators and an AND gate—as do the Word Comparators of the Hue Position Control block 240. Moreover, each Bit Comparator of each Word Comparator of the Phase Control Circuit block 234 has an AND gate, an OR gate, and a NOR gate—as do the Bit Comparators of the Hue Position Control block 240.

The cable 173 which extends from the card reader 232 to the Phase Control Circuit block has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 870, the cable 171 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 872, the cable 169 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 874, the cable 167 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 876, the cable 165 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 878, and the cable 163 has the seven conductors thereof extending to the lower inputs of the AND gates and NOR gates of the Bit Comparators of the Word Comparator 880. The seven conductors of the cable 237, which extends from the counter 246 to the Phase Control Circuit block 234, are connected, respectively, to the upper inputs of the AND gates and NOR gates of each Bit Comparator of each Word Comparator 870, 872, 874, 876, 878 and 880.

The Phase Control Circuit block 234 has three flip-flops 882, 884 and 886; and the "set" terminals of those flip-flops are connected, respectively, to the outputs of the Word Comparators 870, 874 and 878. The "reset" terminals of those flip-flops are connected, respectively, to the outputs of the Word Comparators 872, 876 and 880. The outputs of the flip-flops 882, 884 and 886 are connected, respectively, to the Carrier Generator block 270 by the conductors 264, 266 and 268.

Referring particularly to FIG. 12, which shows in block form the components and connections of the Hue Comparator block 300, the numeral 302 denotes a Hue Zero Crossing Detector block which is connected to the Phase Detector block 276 of FIG. 9 by the conductor 304, and which is connected to the Signal Conditioning And Filtering block 119 by the conductors 134 and 168. The latter two conductors apply to the Hue Zero Crossing Detector the AC and DC components of the output signals of the light sensors 102 and 104 of FIGS. 3 and 8. That Hue Zero Crossing Detector has a 200 kilocycle per second filter therein which passes the modulation frequency that is used in modulating the light passing through the light modulator housing 76 of FIG. 3 and that is part of the AC components of the output signals of the light sensors 102 and 104; but that filter will not pass the lower frequency components of the DC components of those output signals. That

Hue Zero Crossing Detector also has a summing network to sum the AC components of the output signals that are supplied by the conductors 134 and 168 and that are filtered by the filter in that Hue Zero Crossing Detector; and the conductor 304 supplies those filtered and summed signals to the Phase Detector block 276 of FIG. 9. In addition, that Hue Zero Crossing Detector has a Schmitt trigger, or other level-sensing subcircuit, which will apply a signal to the input of a monostable multivibrator 306 whenever the filtered and summed signals from the conductors 134 and 168 pass through zero in the positive-going direction. That monostable multivibrator will respond to each actuation thereof to provide a very short pulse.

The numeral 308 generally denotes a Gate Generator block which is shown in detail in FIG. 19A; and that block has 10 flip-flops and has 10 inputs that are connected to the Hue Reference Generator block 230 by the 10 conductors of cable 301. The outputs of the 10 flip-flops of that Gate Generator block are connected to the upper inputs of the 10 AND gates of a Coincidence Circuits block 309 by a cable 310 which includes 10 conductors; and those AND gates are shown in FIG. 19A. The lower inputs of the AND gates of that Coincidence Circuits block are connected to the output of the Monostable Multivibrator 306 by a conductor 311 and a junction 312. The outputs of the AND gates of the Coincidence Circuits block 309 are connected to the "set" terminals of 10 integrators in an Integrators block 313 by a cable 314 which includes 10 conductors; and those integrators are shown in FIG. 19A. The "reset" terminals of those 10 integrators are connected to the Line Sensing block 460 of FIG. 4 by the conductor 461.

The outputs of the 10 integrators of the Integrators block 313 are connected to a Comparator Reference Selector block 315 by a cable 316 which includes 10 conductors, and are connected to the lower input terminals of the 10 amplitude comparators of an Amplitude Comparators block 317 by a cable 318 which includes 10 conductors; and those amplitude comparators are shown in FIG. 19A. The output of the Comparator Reference Selector block 315 is connected to the lower input terminals of the 10 amplitude comparators of the Amplitude Comparators block 317 by a conductor 319.

The outputs of the 10 amplitude comparators of the Amplitude Comparators block 317 are connected to the upper input terminals of 10 AND gates in an AND Gates block 320 by a cable 321 which has 10 conductors; and those AND gates are shown in FIG. 19A. The outputs of those 10 amplitude comparators also are connected to 10 inputs of a Validity Comparator block 322 by the cable 321 and by a cable 323 which has 10 conductors. The output of that Validity Comparator block is connected to the lower input terminals of the 10 AND gates in the AND Gates block 320 by a conductor 324. The outputs of the 10 AND gates in the AND Gates block 320 are connected to the Digital Code Generator block 556 by the 10 conductors of the cable 305.

The numeral 600 in FIG. 12 generally denotes a Gate Generator block which has five flip-flops and which has five inputs that are connected to the Hue Reference Generator 230 by the five conductors of cable 303; and those flip-flops are shown in FIG. 19B. The outputs of the five flip-flops of Gate Generator block 600 are connected to the upper inputs of the five AND gates of a Coincidence Circuits block 602 by a cable 604 which includes five conductors; and those AND gates are shown in FIG. 19B. The lower inputs of the AND gates of Coincidence Circuits block 602 are connected to the output of the Monostable Multivibrator 306 by the cable 311, the junction 312, and a conductor 606. The outputs of the AND gates of the Coincidence Circuits block 602 are connected to the "set" terminals of the five integrators in an Integrators block 608 by a cable 610 which includes five conductors; and those integrators are shown in FIG. 19B. The "reset" terminals of those five integrators are connected to the Line Sensing block 460 of FIG. 4 by the conductor 461.

The outputs of the five integrators of the Integrators block 608 are connected to a Comparator Reference Selector block

612 by a cable 614 which includes five conductors, and are connected to the upper input terminals of the five amplitude comparators of an Amplitude Comparators block 616 by a cable 618 which includes five conductors; and those amplitude comparators are shown in FIG. 19B. The output of the Comparator Reference Selector block 612 is connected to the lower input terminals of the five amplitude comparators of the Amplitude Comparators block 616 by a conductor 620.

The outputs of the five amplitude comparators of the Amplitude Comparators block 616 are connected to the upper input terminals of five AND gates in an AND Gates block 622 by a cable 624 which has five conductors; and those AND gates are shown in FIG. 19B. The outputs of those five amplitude comparators also are connected to five inputs of a Validity Comparator block 626 by the cable 624 and a cable 628 which has five conductors. The output of that Validity Comparator block is connected to the lower input terminals of the five AND gates in the AND Gates block 622 by a conductor 630. The outputs of the five AND gates in the AND Gates block 622 are connected to the Digital Code Generator block 556 by the five conductors of the cable 307.

FIG. 20 shows an integrator which includes a diode 858, a resistor 860 connected between the cathode of that diode and ground, a resistor 862 and a capacitor 864 connected in series between the cathode of that diode and ground, and an NPN transistor 866 which has the collector-emitter circuit thereof connected in parallel with capacitor 864. The collector of transistor 866 constitutes the output terminal of the integrator; and the base of that transistor constitutes the reset terminal of that integrator. The anode of the diode 858 constitutes the input terminal of that integrator.

The components and connections of the Gate Generator block 308, of the Coincidence Circuits block 309, of the Integrators block 313, of the Comparator Reference Selector block 315, of the Amplitude Comparators block 317, of the Validity Comparator block 322, and of the AND Gates block 320 are shown in greater detail in FIG. 19A; and the Gate Generator block 308 has 10 flip-flops 632, 634, 636, 638, 640, 642, 644, 646, 648 and 650. The uppermost conductor of cable 301 is connected to the set terminal of flip-flop 632 and to the reset terminal of flip-flop 650, the second uppermost conductor of that cable is connected to the set terminal of flip-flop 634 and to the reset terminal of flip-flop 632, the third uppermost conductor of that cable is connected to the set terminal of flip-flop 636 and to the reset terminal of flip-flop 634, the fourth uppermost conductor of that cable is connected to the set terminal of flip-flop 638 and to the reset terminal of flip-flop 636, the fifth uppermost conductor of that cable is connected to the set terminal of flip-flop 640 and to the reset terminal of flip-flop 638, the sixth uppermost conductor of that cable is connected to the set terminal of flip-flop 642 and to the reset terminal of flip-flop 640, the seventh uppermost conductor of that cable is connected to the set terminal of flip-flop 644 and to the reset terminal of flip-flop 642, the eighth uppermost conductor of that cable is connected to the set terminal of flip-flop 646 and to the reset terminal of flip-flop 644, the ninth uppermost conductor of that cable is connected to the set terminal of flip-flop 648 and to the reset terminal of flip-flop 646, and the lower most conductor of that cable is connected to the set terminal of flip-flop 650 and to the reset terminal of flip-flop 648.

The Coincidence Circuits block 309 has 10 AND gates 651, 652, 654, 656, 658, 660, 662, 664, 666 and 668; and the Integrators block 313 has 10 integrators 670, 672, 674, 676, 678, 680, 682, 684, 686 and 688. The Comparator Reference Selector block 315 has an OR gate 299 with 10 inputs, has a differential amplifier 692, and has a resistor 694 which connects the upper input of that differential amplifier to a source of positive biasing voltage. The Amplitude Comparators block 317 has 10 Amplitude Comparators 698, 700, 702, 704, 706, 708, 710, 712, 714 and 716. The Validity Comparator block 322 has an amplifier to a terminal 721 which is connected to a source of negative biasing voltage, has resistors 722, 724, 726,

728, 730, 732, 734, 736, 738 and 740 connecting the outputs of the amplitude comparators 698, 700, 702, 704, 706, 708, 710, 712, 714 and 716 to the input of that amplifier, has a resistor 742 and a Zener diode 744 connecting the output of that amplifier to a terminal 746 which is connected to a source of negative bias voltage, has a diode 748 connected in the forward direction between resistor 742 and the input of that amplifier, and has a diode 750 connected in the reverse direction between the output and the input of that amplifier. The AND Gates block 320 has 10 AND gates 752, 754, 756, 758, 760, 762, 764, 766, 768 and 770; and the lower inputs of those AND gates are connected to the output of amplifier 718, while the upper inputs of those AND gates are connected to the outputs of the Amplitude Comparators 698, 700, 702, 704, 706, 708, 710, 712, 714 and 716. The outputs of the AND gates 752, 754, 756, 758, 760, 762, 764, 766, 768 and 770 are connected to the Digital Code Generator block 556 by the 10 conductors of cable 305.

The components and connections of the Gate Generator block 600, of the Coincidence Circuits block 602, of the Integrators block 608, of the Comparator Reference Selector block 612, of the Amplitude Comparators block 616, of the Validity Comparator block 626, and of the AND Gates block 622 are shown in greater detail in FIG. 19B; and the Gate Generator block 600 has five flip-flops 772, 774, 776, 778 and 780. The uppermost conductor of cable 303 is connected to the set terminal of flip-flop 772 and to the reset terminal of flip-flop 780, the second uppermost conductor of that cable is connected to the set terminal of flip-flop 774 and to the reset terminal of flip-flop 772, the third uppermost conductor of that cable is connected to the set terminal of flip-flop 776 and to the reset terminal of flip-flop 774, the fourth uppermost conductor of that cable is connected to the set terminal of flip-flop 778 and to the reset terminal of flip-flop 776, and the lowermost conductor of that cable is connected to the set terminal of flip-flop 780 and to the reset terminal of flip-flop 778.

The Coincidence Circuits block 602 has five AND gates 782, 784, 786, 788 and 790; and the Integrators block 608 has five integrators 792, 794, 796, 798 and 800. The Comparator Reference Selector block 612 has an OR gate 802 with five inputs, has a differential amplifier 804, and has a resistor 806 which connects the upper input of that differential amplifier to a source of positive biasing voltage. The Amplitude Comparators block 616 has five amplitude comparators 808, 810, 812, 814, and 816. The Validity Comparator block 626 has an amplifier 818, has a resistor 820 connecting the input of that amplifier to a terminal 822 which is connected to a source of negative biasing voltage, has resistors 824, 826, 828, 830 and 832 connecting the outputs of the amplitude comparators 808, 810, 812, 814, and 816 to the input of that amplifier, has a resistor 834 and a Zener diode 836 connecting the output of that amplifier to a terminal 838 which is connected to a source of negative bias voltage, has a diode 840 connected in the forward direction between resistor 834 and the input of that amplifier, and has a diode 842 connected in the reverse direction between the output and the input of that amplifier. The AND Gates block 622 has five AND gates 844, 846, 848, 850, and 852; and the lower inputs of those AND gates are connected to the output of amplifier 818, while the upper inputs of those AND gates are connected to the outputs of the Amplitude Comparators 808, 810, 812, 814 and 816. The outputs of the AND gates 844, 846, 848, 850 and 852 are connected to the Digital Code Generator block 556 by the five conductors of cable 307.

Referring particularly to FIG. 13, which shows in block form the components and connections of the Latitude Comparator block 330 of FIG. 4, the numeral 332 denotes a Latitude Control Subcircuits block which contains five digital to analogue converters of standard and usual form—such as resistor ladders. The numerals 333, 334, 335, 336 and 338 denote comparator blocks which contain level detectors such as Schmitt triggers; and the numeral 342 denotes a Comparator block which contains a level detector such as a Schmitt

trigger. The latter Comparator block has two inputs and two outputs. The upper input of Comparator block 342 is connected to the Color Contrast And Latitude Computer block 366 of FIG. 4 by the conductor 456; and the lower input of that Comparator block is connected to the movable contact of a potentiometer 344 which has the lower terminal grounded and which has the upper terminal thereof connected to a source of positive biasing voltage.

The upper output of the Comparator block 342 is connected to the Digital Code Generator block 556 by the conductor 339, while the lower output of that Comparator block is connected to that Digital Code Generator block by the conductor 349. The Latitude Control Subcircuits block 332 has five inputs of seven conductors each, and those inputs are connected to the card reader 232 by the conductor 231; and that Latitude Control Subcircuits block has five outputs which are connected, respectively, to the upper inputs of the Comparator blocks 333, 334, 335, 336 and 338. The lower inputs of those Comparator blocks are all connected to the Color Contrast And Latitude Computer block 366 of FIG. 4 by the conductor 456. The outputs of the Comparator blocks 333, 334, 335, 336 and 338 are connected to the Digital Code Generator block by the five-conductor cable 337.

Referring particularly to FIG. 10, which shows in block form the components and connections of the Color Contrast And Latitude Computer block 366, the numeral 368 denotes a high speed squaring circuit; and the input of that squaring circuit is connected to the Signal Conditioning And Filtering block 119 by conductor 168, junction 367 and conductor 372. The numeral 370 denotes a second high speed squaring circuit; and the input of that second squaring circuit is connected to the Signal Conditioning And Filtering block 119 by conductor 134, junction 369, and conductor 374. As a result, the squaring circuits 368 and 370 receive the AC components and the DC components of the signals from the light sensors 102 and 104 of FIGS. 3 and 8.

Junctions 376 and 378 connect the output of the squaring circuit 368 to the input of a delay circuit 380, and also coact with a resistor 399 and junctions 390 and 384 to connect the output of that squaring circuit to the input of a sum amplifier 387. That sum amplifier includes an amplifier 386, and a resistor 388 which is connected to the output of the amplifier 386 by a junction 392 and which is connected to the input of that amplifier by the junctions 390 and 384. A resistor 382 connects the output of the delay circuit 380 to the input of the sum amplifier 387. The numeral 394 denotes a rejection filter which has the input thereof connected to the output of the sum amplifier 387 by the junction 392, and which has the output thereof connected to a junction 396.

Junctions 400 and 402 connect the output of the squaring circuit 370 to the input of a delay circuit 404, and also coact with a resistor 424 and junctions 414 and 408 to connect the output of that squaring circuit to the input of a sum amplifier 413. That sum amplifier includes an amplifier 410, and a resistor 412 which is connected to the output of the amplifier 410 by a junction 416 and which is connected to the input of that amplifier by the junctions 414 and 408. A resistor 406 connects the output of the delay circuit 404 to the input of the sum amplifier 413. A rejection filter 418 has the input thereof connected to the output of the sum amplifier 413 by the junction 416, and has the output thereof connected to a junction 420.

The delay circuit 380 will provide a time delay for signals, applied to the input thereof, which is equal to one-half of a cycle of the 200 kilocycle per second modulating frequency used to modulate the light passing through the filters 70, 72 and 74 in FIG. 3; and, similarly, the delay circuit 404 will provide a time delay for signals, applied to the input thereof, which is equal to one-half of a cycle of that modulating frequency. The sum amplifier 387 will sum the delayed signals which pass through the delay circuit 380 with the undelayed signals which pass through the resistor 399; and the rejection filter 394 will reject any summed signals having a frequency

equal to twice the 300 kilocycle per second modulation frequency used to modulate the light from the filters 70, 72 and 74 in FIG. 3. Similarly, the sum amplifier 413 will sum the delayed signals which pass through the delayed circuit 404 with the undelayed signals which pass through the resistor 424; and the rejection filter 418 will reject any summed signals having a frequency equal to twice the 200 kilocycle per second modulation frequency used to modulate the light from the filters 70, 72 and 74 in FIG. 3. The conductor 398 is connected to the junction 396, and the conductor 422 is connected to the junction 420; and those conductors extend to the Line Sensing block 460 of FIG. 4 which has the components thereof shown in FIG. 15.

The numeral 430 in FIG. 10 denotes a low frequency band-pass filter which has the input thereof connected to the junction 376, and which has the output thereof connected to one input of an OR gate 434. The numeral 432 denotes a low frequency band-pass filter which has the input thereof connected to the junction 400, and which has the output thereof connected to the other input of the OR gate 434. Those low frequency band-pass filters will pass DC signals and signals having frequencies below one kilocycle per second; and hence those filters will essentially pass only the low frequency components of the outputs of the squaring circuits 368 and 370.

The numeral 438 denotes a medium speed, Hall effect multiplier which has the upper input thereof connected to the output of the OR gate 434. The numeral 440 denotes another medium speed, Hall effect multiplier; and the lower input of multiplier 440 is connected to the output of an OR gate 436 which has the two inputs thereof connected to the junctions 396 and 420. The output of the multiplier 440 is connected to a junction 455 by a resistor 454; and a resistor 442 and a terminal 444 connect that junction to a voltage reference, such as a battery. An amplifier 450 has the input thereof directly connected to the junction 455; and a junction 452 connects the output of that amplifier to the lower input of the multiplier 438 and to the left-hand input of the multiplier 440. The conductor 456 connects the output of the multiplier 438 to the upper input of Comparator block 342 and to the lower inputs of Comparator blocks 333, 334, 335, 336 and 338 of the Latitude Comparator block 330 of FIG. 13.

Referring particularly to FIG. 15, which shows the components of the Line Sensing block 460 of FIG. 4, the numeral 466 denotes a junction which connects the conductor 398, from the Color Contrast And Latitude Computer 366, to a delay circuit 470. The output of that delay circuit is connected to the upper input of an OR gate 514 by a junction 476, and that output also is connected to the input of a sum amplifier 487 by that junction, a resistor 477, and a junction 480. That sum amplifier includes an amplifier 482, and a resistor 484 which is connected to the output of the amplifier 482 by a junction 486 and which is connected to the input of that amplifier by the junction 480.

The numeral 468 denotes a junction which connects the conductor 422, from the Color Contrast And Latitude Computer 366, to a delay circuit 472. The output of that delay circuit is connected to the lower input terminal of an OR gate 518 by a junction 496, and that output also is connected to the input of a sum amplifier 507 by that junction, a resistor 497, and a junction 500. That sum amplifier includes an amplifier 502, and a resistor 504 which is connected to the output of the amplifier 502 by a junction 506 and which is connected to the output of that amplifier by the junction 500. A conductor 493 connects the junction 466 to a junction 494; and thus directly to the upper input terminal of the OR gate 518, and via a resistor 498 and the junction 500 to the input of the sum amplifier 507. A conductor 473 connects the junction 468 to a junction 474; and thus directly to the lower input terminal of the OR gate 514, and via a resistor 478 and the junction 480 to the input of the sum amplifier 487.

The junction 486 and a junction 488 connect the output of the sum amplifier 487 to the upper input of an OR gate 522; and those junctions, a resistor 490, and junctions 492 and 530

connect the output of that sum amplifier to the input of a sum amplifier 537. The latter sum amplifier includes an amplifier 532, and a resistor 534 which is connected to the output of the amplifier 532 by a junction 536 and which is connected to the input of that amplifier by the junction 530. The output of the sum amplifier 537 is connected to one of the inputs of an OR gate 546.

The junction 506 and a junction 508 connect the output of the sum amplifier 507 to the other input of the OR gate 522; and those junctions, a resistor 510 and junctions 512 and 538 connect the output of that sum amplifier to the input of a sum amplifier 545. The latter sum amplifier includes an amplifier 540, and a resistor 542 which is connected to the output of the amplifier 540 by a junction 544 and which is connected to the input of that amplifier by the junction 538. The output of the sum amplifier 545 is connected to the other input of the OR gate 546. A resistor 516 and the junctions 492 and 530 connect the output of the OR gate 514 to the input of the sum amplifier 537; and a resistor 520 and the junctions 512 and 538 connect the output of the OR gate 518 to the input of the sum amplifier 545.

The numeral 524 denotes a gate generator, which can be an on-off electronic switch such as a Schmitt trigger, that is actuated by signals slightly above zero. The input of that gate generator is connected to the output of the OR gate 522 by a normally-closed pushbutton switch 528. One output of the gate generator 524 is connected to the Integrators blocks 313 and 608 of FIG. 12 by the conductor 461, and is connected to the junction 289 in FIG. 9 by conductor 461, junction 463 and conductor 465. The other output of that gate generator is connected to one of the inputs of an AND gate 529.

The numeral 548 denotes a gate generator, which can be an on-off electronic switch such as a Schmitt trigger, that is actuated by signals slightly above zero. The input of that gate generator is connected to the output of the OR gate 546. The gate generator 548 has two outputs; but one of those outputs is not used, and the other of those outputs is connected to the other input of the AND gate 529. The conductor 531 connects the output of the AND gate 529 to the Digital Code Generator block 556 of FIG. 4.

Referring particularly to FIG. 14, which shows in block form the components and connections of the Digital Code Generator block 556 of FIG. 4, the numeral 558 denotes an AND Gates block which contains 10 AND gates—each of which has two inputs. The 10 conductors, which constitute the cable 305 and which extend from the AND Gates block 320 in FIG. 12, extend, respectively, to the lower inputs of the 10 AND gates of the AND Gates block 558, as shown by FIG. 21. The numeral 352 denotes a NOR gate; and the output of that NOR gate is connected to the upper inputs of the AND gates of the AND Gates block 558, as shown by FIG. 21.

The numeral 561 denotes an AND Gates block which contains five AND gates—each of which has three inputs. The five conductors, which constitute the cable 307 and which extend from the AND Gates block 622 in FIG. 12, extend, respectively, to the upper inputs of the five AND gates of the AND Gates block 561, as shown by FIG. 21. The five conductors, which constitute the cable 337 and which extend from the outputs of the comparators blocks 333, 334, 335, 336 and 338 of FIG. 13, extend, respectively, to the middle inputs of the five AND gates of the AND Gates block 561, as shown by FIG. 21. The conductor 339, which extends from the upper output of the Comparator block 342 in FIG. 13, extends to the lower inputs of the five AND gates of the AND Gates block 561, as shown by FIG. 21.

The numeral 564 denotes a Color Number Decode Matrix block; and that block will include a diode matrix. The numeral 570 denotes a Computer Buffer block and that Computer Buffer block will perform the functions customarily performed by computer buffers. The conductor 531 which is connected to the output of the AND gate 529 in FIG. 15 extends to the Computer Buffer block 570; and the conductor 572 which is connected to the Drum And Scanner Drive block 115

of FIG. 4 also extends to that Computer Buffer block. The output of the Color Number Decode Matrix block 564 is connected to the Computer Buffer block 570 by a cable 573 which includes a plurality of conductors. The output of the Computer Buffer block 570 is connected to the Buffer And Data Record Control block 580 of FIG. 4 by the conductor 576.

As shown by FIG. 21, the AND gates of the AND Gates block 561 are denoted by the numerals 890, 891, 892, 893 and 894. Each of those AND gates has a resistor which connects the output thereof to a source of positive biasing voltage. The AND gates of the AND Gates block 558 are denoted by the numerals 896, 897, 898, 899, 900, 901, 902, 903, 904 and 905; and each of those AND gates has a resistor which connects the output thereof to a source of positive biasing voltage. The NOR gate 352 includes diodes 907, 908, 909, 910, 911 and 912 and also includes an inverter 914 which is connected to the cathodes of all of those diodes.

A branched conductor 918 connects the output of AND gate 890 to diode 907 of NOR gate 352 and to Color Number Decode Matrix block 564, a branched conductor 920 connects the output of AND gate 891 to diode 908 of that NOR gate and to that Color Number Decode Matrix block, a branched conductor 922 connects the output of the AND gate 892 to diode 910 of that NOR gate and to that Color Number Decode Matrix block, a branched conductor 924 connects the output of AND gate 893 to diode 911 of that NOR gate and to that Color Number Decode Matrix block, and a branched conductor 926 connects the output of AND gate 894 to diode 912 of that NOR gate and to that Color Number Decode Matrix block. The branched conductor 349 connects the lower output of comparator block 342 in FIG. 13 to diode 909 of NOR gate 352 and to Color Number Decode Matrix block 564. Conductors 930, 932, 934, 936, 938, 940, 942, 944, 946 and 948, respectively, connect the outputs of AND gates 896, 897, 898, 899, 900, 901, 902, 903, 904 and 905 to Color Number Decode Matrix block 564.

The Hue Position Control block 238 of FIG. 11 has 10 word comparators, as shown by FIG. 17, the Hue Position Control block 240 of FIG. 11 has five word comparators, as shown by FIG. 16, and the Phase Control Circuit block 234 of FIG. 11 has six word comparators, as shown by FIG. 18; and all of those word comparators are identical to the word comparator 241 shown in FIG. 16. That word comparator has 7-bit comparators; and all of those bit comparators are identical to the bit comparator 249 which has the AND gate 258, the OR gate 259, and the NOR gate 260. The upper inputs of that AND gate and of that NOR gate are both connected to conductor 225; and hence both of those inputs will receive the same signal from counter 246 at the same time. Similarly, the lower inputs of AND gate 258 and of NOR gate 260 are both connected to the uppermost conductor of cable 209; and hence both of those inputs will receive the same signal from card reader 232 at the same time.

If the conductor 225 supplies a 0 to the upper inputs of AND gate 258 and of NOR gate 260, and if the uppermost conductor of cable 209 simultaneously supplies a 0 to the lower inputs of those gates, the AND gate 258 will remain quiescent and thus not supply a signal to the upper input of the OR gate 259. However, the NOR gate 260 will respond to the 0's at the upper and lower inputs thereof to supply a signal to the lower input of that OR gate; and that OR gate will then supply a signal to the uppermost input of AND gate 256. If the conductor 225 supplies a 1 to the upper inputs of AND gate 258 and of NOR gate 260, and if the uppermost conductor of cable 209 simultaneously supplies a 0 to the lower inputs of those gates, both AND gate 258 and NOR gate 260 will remain quiescent and not supply a signal to OR gate 259; and that OR gate will then be unable to supply a signal to the uppermost input of AND gate 256. If the conductor 225 supplies a 1 to the upper inputs of AND gate 258 and of NOR gate 260, and if the uppermost conductor of cable 209—in response to a different card in the card reader 232—supplies a 1 to the

lower inputs of those gates, the NOR gate 260 will remain quiescent and thus not supply a signal to the lower input of OR gate 259. However, the AND gate 258 will respond to the 1's at the upper and lower inputs thereof to supply a signal to the upper input of that OR gate; and that OR gate will then supply a signal to the uppermost input of AND gate 256. If the conductor 225 supplies a 0 to the upper inputs of AND gate 258 and of NOR gate 260, and if the uppermost conductor of cable 209—in response to that different card—simultaneously supplies a 1 to the lower inputs of those gates, both AND gate 258 and NOR gate 260 will remain quiescent and not supply a signal to OR gate 259; and that OR gate will then be unable to supply a signal to the uppermost input of AND gate 256. As a result, the bit comparator 249 will supply a signal to the uppermost input of AND gate 256 whenever the signal on conductor 225 matches the signal on the uppermost conductor of cable 209—whether both signals are 0's or 1's. Conversely, that bit comparator will not supply a signal to the uppermost input of AND gate 256 whenever the signal on conductor 225 fails to match the signal on the uppermost conductor of cable 209—whether the signal on conductor 225 is 0 or 1.

The other 6-bit comparators of the word comparator 241 will respond in similar fashion to "matches" and "mismatches" of the signals on the conductors 226, 227, 228, 229, 233 and 235 with the respective signals on the conductors of cable 209; and, when all seven of the bit comparators of that word comparator find a "match," that word comparator will have a signal at all of the seven inputs of the AND gate 256 thereof and that AND gate will be applying a signal to the Gate Generator 600 in FIG. 12 via the uppermost conductor of cable 303. However, if any one of those 7-bit comparators does not find a match, the word comparator 241 will not have a signal at all of the seven inputs of the AND gate 256 thereof and that AND gate will be unable to supply a signal to the Gate Generator 600 in FIG. 12. The 7-bit word which is developed by the card reader 232 and which is applied to the word comparator 241 by the seven conductors of cable 209 will be fixed and unchanging, but the 7-bit word which is developed by the counter 246 and which is applied to the word comparator 241 by the seven conductors 225, 226, 227, 228, 233 and 235 will change at the rate of 24 megacycles per second; and each 7-bit word will match at one of the 120 counts of the counter 246.

The word comparators 243, 245, 247 and 248 will, respectively, check the "matches" and "mismatches" of the 7-bit words from counter 246 with the 7-bit words on the cables 211, 213, 215 and 217 from the card reader 232; and each of those word comparators will find a match at one of the 120 counts of the counter 246. Similarly, the word comparators 587, 588, 589, 590, 591, 592, 593, 594, 595 and 596 of FIG. 17 will, respectively, check the "matches" and "mismatches" of the 7-bit words on the conductors 218, 219, 220, 221, 222, 223 and 224 from counter 246 with the 7-bit words on the cables 183, 185, 187, 189, 191, 193, 197, 199, 201 and 203 from the card reader 232; and each of those word comparators will find a match at one of the 120 counts of the counter 246. In the same way, the word comparators 870, 872, 874, 876, 878 and 880 of FIG. 18 check the "matches" and "mismatches" of the 7-bit words on the cables 173, 171, 169, 167, 165 and 163 from the card reader 232; and each of those word comparators will find a match at one of the 120 counts of the counter 246.

The "matches" found by the word comparators 870, 872, 874, 876, 878 and 880 will cause the flip-flops 882, 884 and 886 of FIG. 18 to develop the phase-displaced square waves of FIG. 22; and the Carrier Generator block 270 of FIG. 4 will convert those square waves to sine waves and will apply them to the Phase Detector block 276 of FIG. 9. That Phase Detector block includes a phase sensitive detector 269 and a phase sensitive detector 278; and the conductor 271 is connected to the phase sensitive detector 269 while the conductor 273 is connected to the phase sensitive detector 278. The phase sensitive detector 269 is connectable to the integrator 288 by the

gate 282, and the phase sensitive detector 278 is connectable to the integrator 290 by the gate 286. For purposes of illustration, it will be assumed that the filter 70 in FIG. 3 essentially passes only red light, that the filter 72 essentially passes only blue light, and that the filter 74 essentially passes only green light; and it will further be assumed that the conductor 271 extends via junction 279 and conductor 280 to the light modulator in the Light Modulators block 110 which modulates the red light from filter 70, and that the conductor 273 extends via junction 272 and conductor 277 to the light modulator in the Light Modulators block 110 which modulates the blue light from filter 72. The conductor 274 will extend via junction 281 and conductor 283 to the light modulator in the Light Modulators block 110 which modulates the green light from filter 74; but, while conductor 275 will extend to the Phase Detector block 276, it will not be connected to any active component in that block. The conductor 304 is connected to both of the phase sensitive detectors 269 and 278 in the Phase Detector block 276; and the operation of both those phase sensitive detectors are phased to prevent crosstalk between the light intensity control circuits.

The conductor 218, the conductor 225, and one of the conductors of cable 237 are connected to the output of the first flip-flop of the counter 246, conductors 219 and 226 and a second conductor of cable 237 are connected to the output of the second flip-flop of that counter, conductors 220 and 227 and a third conductor of cable 237 are connected to the output of the third flip-flop of that counter, conductors 221 and 228 and a fourth conductor of cable 237 are connected to the output of the fourth flip-flop of that counter, conductors 222 and 229 and a fifth conductor of cable 237 are connected to the output of the fifth flip-flop of that counter, conductors 223 and 233 and a sixth conductor of cable 237 are connected to the output of the sixth flip-flop of that counter, and conductors 224 and 235 and the seventh conductor of cable 237 are connected to the output of the seventh flip-flop of that counter. In developing the 7-bit words which the counter 246 supplies to the Hue Position Control blocks 238 and 240 and to the Phase Control Circuits block 234, the seventh flip-flop of that counter experiences two changes of state every 5 microseconds; and the sixth, fifth, fourth, third, second and first flip-flops of that counter respectively experience 4, 8, 16, 32, 64, and 120 changes of state every 5 microseconds. To keep the various flip-flops of that counter from supplying transients, which could act as false signals, to the Hue Position Control blocks 238 and 240 and to the Phase Control Circuits block 234, the clock 244 and the counter 246 will be equipped with a "strobe" which will permit that counter to supply signals to the Hue Position Control blocks 238 and 240 and to the Phase Control Circuits block 234 only after that counter has changed state and all transients have disappeared. Any type of digital "strobe" can be used, as long as it enables the clock 244 to supply pulses to the counter 246 at a rate of 200 kilocycles per second, enables the first flip-flop of that counter to change states at that rate and to apply signals to the Hue Position Control blocks 238 and 240 and to the Phase Control Circuits block 234 at that rate, and enables that counter to reset itself at the end of each count of 120.

BRIEF DESCRIPTION OF OPERATION OF COLOR IDENTIFICATION UNIT

The Drum And Scanner Drive block 115 in FIG. 4 will rotate the drum 52, and hence the document 53 carried by that drum, at a predetermined speed, it will cause the scanner 60 in FIG. 2 to move axially along the guide rods 54 and 56 at a predetermined speed, and it will supply signals to the Digital Code Generator block 556 that will indicate the circumferential and axial position of the particular area on the document 53 which is being scanned at any given instant. The light sources 64, 66 and 68 will coact with the filters 70, 72 and 74 and with the modulators in the light modulator housing 76 and with the lens systems 84, 86 and 88 to form the spot 90 of light

at the surface of the document 53. The base material or the colored areas, or both, of that document will reflect light toward the lens system 92; and that light will pass through that lens system and through the Wollaston prism 94 which will develop two cones of orthogonally-polarized light that will form the overlapping spots 101 and 105 of light shown in FIG. 6. Portions of both of those spots of light will pass through the aperture 98 in the aperture plate 96 and will be additionally polarized by the Wollaston prism 100, and will be used to form a spot of light at the inlet of the light sensor 102 and a second spot of light at the inlet of the light sensor 104. The double polarization provided by the Wollaston prisms 94 and 100 will permit the light sensor 102 to "see" only the portion of the light which forms the light spot 105 and which passes through the aperture 98, and will permit the light sensor 104 to see only the portion of light which forms the light spot 101 and which passes through that aperture.

The Signal Conditioning And Filtering block 119 will receive the electric signals developed by the light sensors 102 and 104, will amplify those signals, will subtract those signals from a fixed voltage to form two difference signals, and will apply those difference signals to the Hue Comparator block 300 and to the Color Contrast And Latitude Computer block 366. In addition, the Signal Conditioning And Filtering block 119 will filter those difference signals and supply them to the Gain Control Circuits block 117. The latter block will subtract, as well as add, the two amplified and filtered difference signals from the Signal Conditioning And Filtering block 119; and it will vary the gains of the light sensors 102 and 104 to balance those gains, and also to hold those gains at levels which will produce average difference signals that are zero.

The electric signals developed by the light sensors 102 and 104 will contain lightness information in the form of a varying DC signal and will contain color information in the form of an AC waveform at the 200 kilocycle per second frequency used to modulate the light passing through the filters 70, 72 and 74 in FIG. 3. The phase of that AC waveform will be a function of the hue of the light reflected from the document 53, and the amplitude of that AC waveform will be a function of the saturation of the pigment reflecting that light toward those light sensors. The DC levels of the difference signals developed by the light sensor 102 and 104 and associated circuits will be proportional to the difference in lightness of the base material and of that pigment.

The electric signals developed by the light sensor 102 and appearing at the junction 130 of the Signal Conditioning And Filtering block 119 can be represented by the term:

$$L + 1.41 S \sin \omega t$$

where L is the lightness difference vector 40 of the pigment "seen" by that light sensor, where S is the saturation vector 34 of that pigment, and where ωt is the 200 kilocycle per second frequency used to modulate the light passing through the filters 70, 72 and 74 in FIG. 3. The electric signal developed by the light sensor 104 and appearing at the junction 166 of the Signal Conditioning And Filter block 119 can be represented by the term:

$$L_1 + 1.41 S_1 \sin \omega t$$

where L_1 is the lightness difference vector 40 of the pigment "seen" by that light sensor, where S_1 is the saturation vector 34 of that pigment, and where ωt is the 200 kilocycle per second frequency used to modulate the light passing through the filters 70, 72 and 74 in FIG. 3. The squaring circuit 368 of FIG. 10 will receive the amplified signals from amplifier 158 in FIG. 8 via conductors 168 and 372, and will square the term which represents the electric signals developed by the light sensor 104; and the squaring circuit 370 will receive the amplified signals from amplifier 126 in FIG. 8 via conductors 134 and 374, and will square the term which represents the electric signals developed by the light sensor 102. The term at the output of squaring circuit 370 will be:

$$L^2 + 2.82 L S \sin \omega t + 2.5^2 \sin^2 \omega t$$

and the term at the output of squaring circuit 368 will be:

$$(L_1)^2 + 2.82 L_1 S_1 \sin \omega t + 2(S_1)^2 \sin^2 \omega t$$

The lightness vectors L and L_1 represent the DC components of the electric signals developed by the light sensors 102 and 104 whereas the saturation vectors S and S_1 and the phase vector $\sin \omega t$ represent the AC components of those electric signals; and the Low Frequency Band Pass Filters 430 and 432 will pass the DC components, namely, the L^2 and $(L_1)^2$ of those electric signals, but will not pass the AC components, namely, the $2.82 L S \sin \omega t$ and $2.82 L_1 S_1 \sin \omega t$ and $2S^2 \sin^2 \omega t$ and $2(S_1)^2 \sin^2 \omega t$, of those signals. The OR gate 434 will respond to the largest DC component to apply a signal to the input of the multiplier 438; and hence that multiplier will, whenever the light sensor 102 or the light sensor 104 "sees" an illuminated area on the document 53, have L^2 or $(L_1)^2$ at the upper input thereof.

The term $\sin^2 \omega t$ is equal to $\frac{1 - \cos 2\omega t}{2}$; and hence the term at the output of the squaring circuit 370 effectively is:

$$L^2 + 2.82 L S \sin \omega t + S^2 - S^2 \cos 2\omega t$$

and the term at the output of the squaring circuit 368 effectively is:

$$(L_1)^2 + 2.82 L_1 S_1 \sin \omega t + (S_1)^2 - (S_1)^2 \cos 2\omega t$$

The delay circuit 380 will delay the squared signals from the squaring circuit 368 by a time interval equal to one-half of a cycle of the 200 kilocycle per second frequency used to modulate the light passing through the filters 70, 72 and 74 in FIG. 3; and the resultant delay will effectively reverse the polarity of the 200 kilocycle per second AC components of both signals. Similarly, the delay circuit 404 will delay the squared signals from the squaring circuit 370 by a time interval equal to one-half of a cycle of the 200 kilocycle per second frequency used to modulate the light passing through the filters 70, 72 and 74 in FIG. 3; and the resulting delay will reverse the polarity of the 200 kilocycle per second AC components of those signals. This means that the term at the output of the delay circuit 404 is:

$$L^2 - 2.82 L S \sin \omega t + S^2 - S^2 \cos 2\omega t$$

and that the term at the output of the delay circuit 380 is:

$$(L_1)^2 - 2.82 L_1 S_1 \sin \omega t + (S_1)^2 - (S_1)^2 \cos 2\omega t$$

The sum amplifier 387 will add the delayed term from the delay circuit 380 to the undelayed term from the squaring circuit 368, and the sum amplifier 413 will add the delayed term from the delay circuit 404 to the undelayed term from the squaring circuit 370; and the sum at the output of sum amplifier 413 will be:

$$2L^2 + 2S^2 - 2S^2 \cos^2 \omega t$$

while the sum at the output of sum amplifier 387 will be:

$$2(L_1)^2 + 2(S_1)^2 - 2(S_1)^2 \cos 2\omega t$$

The rejection filters 394 and 418 are designed to reject signals having a frequency equal to or close to twice the 200 kilocycle per second frequency used to modulate the light passing through the filters 70, 72 and 74 in FIG. 3; and hence those rejection filters will effectively eliminate the $2S^2 \cos 2\omega t$ and the $2(S_1)^2 \cos 2\omega t$ of the immediately preceding terms. As a result, the output of the rejection filter 418 will be $2L^2 + 2S^2$, and the output of the rejection filter 394 will be $2(L_1)^2 + 2(S_1)^2$. Because $L^2 + S^2 = C^2$ where C is the contrast vector of the pigment "seen" by the light sensor 102, and because $(L_1)^2 + (S_1)^2 = (C_1)^2$ where C_1 is the contrast vector of the pigment "seen" by the light sensor 104, the outputs of the rejection filters 394 and 418 will be functions of the contrast vectors of the pigments "seen" by the light sensors 104 and 102. The OR gate 436 will respond to the largest signal supplied to the inputs thereof to supply a signal to the lower input of the multiplier 440 which represents $2C^2$ or $2(C_1)^2$. That multiplier will coact with the voltage reference connected to the terminal 444 and with the amplifier 450 to develop a signal $\frac{1}{C^2}$ or $\frac{1}{(C_1)^2}$ at the junction 452—and thus at the lower input of multiplier 438 and at the left-hand input of multiplier 440. The $\frac{1}{C^2}$ or $\frac{1}{(C_1)^2}$ signal applied to the lower input of multiplier 438 will coact with the L^2 or $(L_1)^2$ signal applied to the upper input of the latter multiplier to develop a signal $\frac{L^2}{C^2}$ or $\frac{(L_1)^2}{(C_1)^2}$. The

$\frac{L^2}{C^2}$ signal equals the square of the cosine of the latitude angle of the pigment seen by the light sensor 102, and the $\frac{(L_1)^2}{(C_1)^2}$

signal equals the square of the cosine of the latitude angle of the pigment seen by the light sensor 104; and, as pointed out in the section entitled PROGRAMMING OF COLOR IDENTIFICATION UNIT, the square of the cosine of the latitude angle of a pigment is important in distinguishing between pigments which have a given hue and which have a low value of lightness 36 and saturation 34 and pigments which have a similar hue but which have a high value of lightness 36 and saturation 34 in the color solid 20 of FIG. 1. The conductor 456 applies the signal at the output of multiplier 438 to the upper input of the comparator 342 and to the lower inputs of each of the comparators 333, 334, 335, 336 and 338 of FIG. 13—and thus applies to those inputs a signal that is a function of the latitude level of the pigments "seen" by the light sensors 102 and 104.

The $2L^2 + 2S^2$ signal at the output of rejection filter 418 is applied to the junction 468 in FIG. 15; and the $2(L_1)^2 + 2(S_1)^2$ signal at the output of rejection filter 394 is applied to the junction 466 in FIG. 15. The $2L^2 + 2S^2$ signal is equal to $2C^2$; and it is applied to the input of amplifier 482 and to the lower input of OR gate 514, and it is delayed by delay circuit 472 and is then applied to the input of amplifier 502 and to the lower input of OR gate 518. The $2(L_1)^2 + 2(S_1)^2$ signal is equal to $2(C_1)^2$; and it is applied to the input of amplifier 502 and to the upper input of OR gate 518, and it is delayed by delay circuit 470 and is then applied to the input of amplifier 482 and to the upper input of OR gate 514. The time delay provided for the $2C^2$ and $2(C_1)^2$ signals will be short enough to enable the waveforms for the delayed $2C^2$ and $2(C_1)^2$ signals to be coextensive in part with the waveforms for the undelayed $2C^2$ and $2(C_1)^2$ signals. As a result, the delayed and undelayed waveforms in the Line Sensing block 460 will resemble waveforms which the light sensors 102 and 104 would develop if they "saw" four areas on the document 53 which were arranged in the manner shown by FIG. 33. The numeral 960 in FIG. 33 denotes an area "seen" by light sensor 102, the numeral 962 denotes an area "seen" by light sensor 104, the numeral 963 denotes the simulated area obtained by delaying the signal from the light sensor 102, and the numeral 964 denotes the simulated area obtained by delaying the signal from the light sensor 104.

Whenever both the light sensors 102 and 104 "see" the base material of the document 53, the $2C^2$ signal and the $2(C_1)^2$ signal will effectively be zero; and hence the signals at the inputs of both of the gate generators 548 and 524 will be zero. Those gate generators are "on-off" electronic switches that have threshold values which are high enough to keep a signal, due to a smudge or erasure on the document 53, from turning those gate generators "on"; but those threshold values must be low enough to enable signals, due to even faint lines or colored areas on the document 53, to turn those gate generators "on." As a result, the Line Sensing block 460 of FIG. 4 will leave the gate generators 524 and 548 thereof "off" whenever the light sensors 104 and 102 both "see" the base material of the document 53. In its "off" state the gate generator 548 develops a signal at the upper output thereof and applies that signal to the lower input of AND gate 529, but in its "off" state the gate generator 524 does not develop a signal at the lower output thereof and thus can not apply a signal to the upper input of that AND gate; and hence that AND gate will not be able to supply a signal to the Computer Buffer block 570 of FIG. 14 when both gate generators are "off." Because that Computer Buffer block will not receive such a signal, it will keep the Buffer And Data Record Control block 580 from supplying a signal to the Recorder block 582; and this is desirable, because the data to be recorded by the Recorder block 582 includes the locations and color values of the colored areas, and the locations of the lines, on the document 53 but does not include the mere presence of the base material of that document.

The summing amplifier 487 generates a signal proportional to the sum of contrasts which appear in the areas 960 and 964 of FIG. 33. Similarly, the summing amplifier 507 generates a signal proportional to the sum of contrasts which appear in the areas 962 and 963. If a line or area which contrasts with the base material appears in any of the four areas, then either the sum amplifier 487 or 507 will apply a signal to the OR gate 522 which will enable that OR gate to apply a signal to the gate generator 524. Also, the sum amplifier 487, the OR gate 514, the resistors 490 and 516, and the sum amplifier 537 will coact to generate a signal which is proportional to the difference in contrast which appears in the areas 960 and 964. Similarly, the sum amplifier 507, the OR gate 518, the resistors 510 and 520, and the sum amplifier 545 will coact to generate a signal which is proportional to the difference in contrast which appears in the areas 962 and 963. If a difference of contrast appears in the areas 960 and 964, or if a difference of contrast appears in the areas 962 and 963, then either the sum amplifier 537 of 545 will apply a signal to the OR gate 546 which will enable that OR gate to apply a signal to the gate generator 548.

Whenever a colored area or line on the document 53 passes into the areas 962 or 960, signals will appear at the outputs of the OR gates 522 and 546 which are applied to the gate generators 524 and 548, respectively. Those gate generators will respond to those signals to turn "on"; and in its "on" state the gate generator 524 will apply a signal to the upper input of AND gate 529, but in its "on" state the gate generator 548 will not apply a signal to the lower input of that AND gate. At such time, the AND gate 529 will not apply a signal to the Computer Buffer block 570 in FIG. 14; and hence the Computer Buffer block will keep the Buffer And Data Record Control block 580 from supplying a signal to the Recorder block 582.

As the colored area or line on the document 53 passes into the areas 963 and 964, a condition will occur when the contrast in the areas 960 and 964 will be equal, and the contrast in the areas 962 and 963 will also be equal. This condition will occur when the four areas 960, 962, 963 and 964 are all within a colored area, or when the areas 960 and 964 are positioned equal distances across a line center and the areas 962 and 963 are also positioned equal distances across a line center. At this time, the OR gate 522 will respond to the signals from amplifier 487 or 507 to continue to supply a signal to the gate generator 524. Also, the amplifier 487, OR gate 514, resistors 490 and 516, and sum amplifier 537 will coact to generate a zero signal. Similarly, the amplifier 507, OR gate 518, resistors 510 and 520, and sum amplifier 545 will coact to generate a zero signal. The OR gate 546 will respond to those zero signals to supply a zero signal to the gate generator 548. The gate generator 524 will respond to the signal applied to the input thereof to turn "on" and develop a signal at the lower output thereof and to apply that signal to the upper input of AND gate 529; and the gate generator 548 will respond to the zero signal applied to the input thereof to turn "off" and develop a signal at the upper output thereof and to apply that signal to the lower input of that AND gate. As a result, the AND gate 529 will apply a signal to the Computer Buffer block 570 of FIG. 14 via conductor 531; and that Computer Buffer block will act through the Buffer Data And Record Control block 580 to cause the Recorder block 582 to start recording the information supplied to that Computer Buffer block by the Color Number Decode Matrix block and by the Drum And Scanner Drive block 115.

The Line Sensing block 460 of FIG. 4 will cause the signal at the output of the AND gate 529 thereof to disappear as soon as a difference occurs in the areas 960 and 964, or in the areas 962 and 963, and if that signal disappears almost immediately after it is developed, the signal supplied to the Recorder block 582 will show that the light sensors 102 and 104 had been "seeing" a line on the document 53. On the other hand, if that signal at the output of the AND gate 529 continues for an appreciable period of time, the signal supplied to the Recorder block 582 will show that the light sensors 102 and 104 had been "seeing" a colored area on the document 53.

It will thus be apparent that whenever the four areas 960,

962 963 and 964 are on the base material of the document 53, or that whenever all of those four areas are not entirely within a colored area or are not positioned at the center of a line, the AND gate 529 will not supply a signal to the Computer Buffer block 570 of FIG. 14; and that Computer Buffer block will keep the Buffer And Data Record Control block 580 from supplying a signal to the Recorder block 582. On the other hand whenever the four areas 960, 962, 963 and 964 are positioned entirely within a colored area, or those areas are positioned at the center of a line on the document 53, and AND gate 529 will supply a signal to the Computer Buffer block 570 of FIG. 14; and that Computer Buffer block will act through the Buffer And Data Record Control block 580 to cause the Recorder block 582 to start recording the information supplied to that Computer Buffer block 570 by the Color Number Decode Matrix block 564 and by the Drum And Scanner Drive block 115. Also, the duration of the signal which the AND gate 529 supplies will indicate whether a line or a colored area had been sensed.

Whenever it is in its "off" state—as when both of the light sensors 102 and 104 "see" just the base material of the document 53—the gate generator 524 develops a signal at the upper output thereof and applies that signal to the upper inputs 284 and 287, respectively, of the gates 282 and 286 in FIG. 9 via conductor 461, junction 463, conductor 465 and junction 289; and it also applies that signal to the reset terminals of the integrators in the Integrators blocks 313 and 608 of FIG. 12 by conductor 461. The signal applied to the upper inputs 284 and 287, respectively, of the gates 282 and 286 in FIG. 9 is important; because it permits those gates to pass to the integrators 288 and 290 any signals from the phase sensitive detectors 269 and 278 of the Phase Detector block 276. The gates 282 and 286 are intended to, and do, isolate those integrators from those phase sensitive detectors whenever either of the light sensors 102 and 104 "sees" a colored area or a line on the document 53, and thus keep the signals developed by that light sensor—as it "sees" that colored area or line—from causing either of the lamp drivers 292 and 294 to change the intensity of the light emitted by the light source driven by that lamp driver. However, whenever both of the light sensors 102 and 104 "see" the base material of the document 53, the signal from the upper output of the gate generator 524 will cause the gates 282 and 286 to permit the phase sensitive detectors of the Phase Detector block 276 to supply signals to the integrators 288 and 290; and these integrators will supply whatever signals are needed to enable the lamp drivers 292 and 294 to adjust the intensities of the light from the light sources 64 and 66 so the light reflected from the base material will be essentially white.

The signal which the upper output of the gate generator 524 will apply to reset terminals of the integrators of the Integrators blocks 313 and 608 of FIG. 12 also is important, because it will effectively reset those integrators. As a result, those integrators will be reset and held at reset whenever the base material is "seen" by the light sensors 102 and 104.

The $2C^2$ signal and the $2(C_1)^2$ signal supplied, respectively, to the junctions 468 and 466 in FIG. 15 are signals which are based upon the contrast values of the pigment "seen" by the light sensors 102 and 104, respectively; and the use of signals based upon contrast values is important. Specifically, the use of such signals makes it possible to provide detection of lines or boundaries on the document 53 independently of the hue values, the lightness values or the saturation values of the data printed or drawn on that document; because the basic factor relied upon in the sensing of the presence of a line or the boundary of an area by the use of signals based upon contrast values is the contrast of that line or area with respect to the base material of the document. The use of signals based upon contrast values is additionally important because it permits the threshold levels of the gate generators 524 and 548 to be set at values which will enable the color identification unit to ignore smudges or erasures on the document 53; and hence enables the information stored within the Recorder 582 to be used to produce documents which will not show the smudges or erasures on the original document 53.

Whenever the gate generator 524 is in its "on" state—as when either of the light sensors 102 and 104 "sees" part of a colored area or part of a line on the document 53—that gate generator will not develop a signal at the upper output thereof; and hence a signal will not be applied to the upper inputs 284 and 287, respectively, of the gates 282 and 286 in FIG. 9, and a signal will not be applied to the reset terminals of the integrators in the Integrators blocks 313 and 608 in FIG. 12. At such time, the integrators 288 and 290 and the lamp drivers 292 and 294 of FIG. 9 will be effectively isolated from the phase sensitive detectors 269 and 278 of the Phase Detector block 276; and the integrators of the Integrators blocks 313 and 608 of FIG. 12 will be able to integrate any signals from the AND gates of the Coincidence Circuits 309 and 602.

The clock 244 of FIG. 11 will develop bits at the rate of 24 megacycles per second, and it will supply those bits to the counter 246; and that counter will respond to those bits to form 7-bit words which change at the rate of 24 megacycles per second. That counter will supply those 7-bit words to the Hue Position Control block 238, to the Hue Position Control block 240, and to the Phase Control Circuit block 234. In addition, that counter will count to 120 and then reset itself for a further count of 120.

The Phase Control Circuit block 234 will respond to the 7-bit words from the counter 246 to develop three square waves which are displaced in phase; and those three square waves will usually be displaced 120° from each other, as shown by FIG. 22. Those square waves are converted to phase-displaced sine waves by the Carrier Generator block 270 of FIG. 4, and are supplied to the light modulators in the light modulator housing 76 and to the phase sensitive detectors in the Phase Detector block 276 of FIG. 9. The light modulators within the light modulator housing 76 will respond to the phase-displaced sine waves to modulate the amplitudes of the light forming the spot of red light, the spot of blue light, and the spot of red light which interact to form the spot 90 of light at the surface of the document 53. The waveforms which the signals from the Carrier Generator 270 of FIG. 4 cause the modulators of the Light Modulator block 110 of FIG. 4 to develop are shown in FIG. 7.

The Hue Position Control block 238 will respond to the 7-bit words from the counter 246 to cause the 10 word comparators thereof to successively apply signals to the 10 flip-flops in the Gate Generator block 308 of FIG. 12; and those 10 flip-flops will successively apply signals to the upper inputs of the 10 AND gates in the Coincidence Circuits block 309 of FIGS. 12 and 19A. Typical signals which those 10 flip-flops apply to the upper inputs of those AND gates are shown in FIG. 30—the numeral 1010 denoting the signal applied to the AND gate 651 by the flip-flop 632, the numeral 1012 denoting the signal applied to the AND gate 652 by the flip-flop 634, the numeral 1014 denoting the signal applied to the AND gate 654 by the flip-flop 636, the numeral 1016 denoting the signal applied to the AND gate 656 by the flip-flop 638, the numeral 1018 denoting the signal applied to the AND gate 658 by the flip-flop 640, the numeral 1020 denoting the signal applied to the AND gate 660 by the flip-flop 642, the numeral 1022 denoting the signal applied to the AND gate 662 by the flip-flop 644, the numeral 1024 denoting the signal applied to the AND gate 664 by the flip-flop 646, the numeral 1026 denoting the signal applied to the AND gate 666 by the flip-flop 648, and the numeral 1028 denoting the signal applied to the AND gate 668 by the flip-flop 650.

The Hue Position Control block 240 will respond to the 7-bit words from the counter 246 to cause the five word comparators thereof to successively apply signals to the five flip-flops in the Gate Generator block 600 of FIGS. 12 and 19B; and those five flip-flops will successively apply signals to the upper inputs of the five AND gates in the Coincidence Circuits block 602 of FIGS. 12 and 19B. Typical signals which those five flip-flops apply to the upper inputs of those AND gates are shown in FIG. 32—the numeral 1030 denoting the signal applied to the AND gate 782 by the flip-flop 772, the

numeral 1032 denoting the signal applied to the AND gate 784 by the flip-flop 774, the numeral 1034 denoting the signal applied to the AND gate 786 by the flip-flop 776, the numeral 1036 denoting the signal applied to the AND gate 788 by the flip-flop 778, and the numeral 1038 denoting the signal applied to the AND gate 790 by the flip-flop 780.

The waveforms 1010, 1012, 1014, 1016, 1018, 1020, 1022, 1024, 1026, 1028, 1030, 1032, 1034, 1036, and 1038 are repetitive at the 200 kilocycle per second rate; and a stable time relationship is maintained between each of those waveforms and the waveforms 326, 327, 328 of FIG. 7 which represent the intensity modulation of the red, blue, and green light forming the spot 90 of light. The counter 246 serves as a basis for phase measurement of a 200 kilocycle per second signal by the time relationship of the positive-going zero crossing of that 200 kilocycle per second signal and the reset time of the counter. As an example, the positive-going zero crossing of the AC component of waveform 326 occurs simultaneously with the reset of the counter 246; and the waveform 326 is thus said to have a phase angle of 0°, and that zero phase angle is represented by the vector 31 in FIG. 1. The positive-going zero crossing of the AC component of waveform 327 occurs 40 counts after the reset of the counter 246, and is thus said to have a 120° lag. The positive-going zero crossing of the AC component of the waveform 328 occurs 80 counts after the reset of the counter 246, and is thus said to have a 240° lag. The gate waveforms which are generated by the Gate Generator block 308 and which are shown in FIG. 30, and the gate waveforms which are generated by the Gate Generator block 600 and which are shown in FIG. 32, are similarly said to have phase angle lags. The "on" periods of those gate or pulse waveforms represent a range of phase angles, herein called "angle slots," which are shown in polar form in FIGS. 29 and 31. Each count of the counter 246 thus corresponds to a 3° phase lag when so related to a 200 kilocycle per second signal.

Where the card reader 232 of FIG. 11 programs the Hue Position Control block 238 to provide the 10 "angle slots" shown in FIG. 29 and programs the Hue Position Control block 240 to provide the five "angle slots" shown in FIG. 31, the signal 1030 in FIG. 32 will be initiated 57° before the start of each cycle of the counter 246, the signal 1010 in FIG. 30 will be initiated 3° before the start of each cycle, the signal 1030 in FIG. 32 will terminate and the signal 1032 will be initiated 30° after the start of each cycle, the signal 1010 will terminate and the signal 1012 will be initiated 33° after the start of each cycle, the signal 1012 will terminate and the signal 1014 will be initiated 51° after the start of each cycle, the signal 1014 will terminate and the signal 1016 will be initiated 69° after the start of each cycle, the signal 1016 will terminate and the signal 1018 will be initiated 111° after the start of each cycle, the signal 1018 will terminate and the signal 1020 will be initiated 138° after the start of each cycle, the signal 1032 in FIG. 32 will terminate and the signal 1034 will be initiated 150° after the start of each cycle, the signal 1034 will terminate and the signal 1036 will be initiated and the signal 1020 in FIG. 30 will terminate and the signal 1022 will be initiated 180° after the start of each cycle, the signal 1036 in FIG. 32 will terminate and the signal 1038 will be initiated 210° after the start of each cycle, the signal 1022 in FIG. 30 will terminate and the signal 1024 will be initiated 225° after the start of each cycle, the signal 1024 will terminate and the signal 1026 will be initiated 273° after the start of each cycle, the signal 1038 in FIG. 32 will terminate and a further signal 1030 will be initiated 303° after the start of each cycle, the signal 1026 in FIG. 30 will terminate and the signal 1028 will be initiated 318° after the start of each cycle, and the signal 1028 will terminate and a further signal 1010 will be initiated 357° after the start of each cycle.

As long as the light sensors 102 and 104 "see" only the base material of the document 53, the outputs developed by those light sensors will essentially provide a DC signal; and the solid line 1040 in FIG. 23 indicates such a DC signal. That DC

signal will represent white light; and it will constitute the vectoral sum of the red signal 1042, of the blue signal 1044, and of the green signal 1046 in FIG. 23. The lines 1048 and 1050 in FIG. 23 indicate the saturation vector *S* of the red, blue and green signals 1042, 1044 and 1046, which corresponds to twice the RMS value of those sine waves; and the line 1052 indicates the average value of each of those signals. If the line 1052 is considered to have a value of one, the saturation vector *S* will have a value of 1 41/100, and the line 1040 will have a value of three.

If the spot 90 of light strikes an area of the document 53 which is yellow and which absorbs all blue light and which reflects all red and green light, the light sensors 102 and 104 will "see" a yellow light and will respond to that yellow light to develop the AC signal denominated as 988 in FIG. 24. That signal will be the sum of the AC waveform 990 corresponding to the modulated green light and of the AC waveform 992 corresponding to the modulated red light. The AC signal 988 will have a positive-going zero crossing at 300°, as shown particularly by FIG. 24; and the Hue Zero Crossing Detector block 302 of FIG. 12—which receives signals from the Signal Conditioning And Filtering block 119 of FIG. 4 via the conductors 134 and 168—will supply a signal to the Monostable Multivibrator block 306 of FIG. 12 at the instant the AC signal 988 of FIG. 24 crosses zero in the positive-going direction.

The 0° in FIG. 24 represents the start of a 120 count by the counter 246 in FIG. 11; and the 300° in FIG. 24 corresponds to a count of 100 of that counter. Since that counter counts to 120 before it resets itself, the AC signal 988 in FIG. 24 experienced a positive-going zero crossing prior to the end of a full cycle of counting of the counter 246. During the 300° between the 0° and the positive-going zero crossing of the AC signal 988 in FIG. 24, the counter 246 supplied 7-bit words to all of the word comparators 587, 588, 589, 590, 591, 592, 593, 594, 595 and 596 of the Hue Position Control block 238 of FIG. 17; and the word comparator 588 responded to those 7-bit words plus 7-bit words from the card reader 232 to reset the flip-flop 632, and the word comparators 589, 590, 591, 592, 593, 594 and 595 responded to those 7-bit words plus 7-bit words from the card reader 232 to successively set and reset the flip-flops 634, 636, 638, 640, 642, 644 and 646 and to set the flip-flop 648 of FIG. 19A, but the word comparators 587 and 596 did not respond to those 7-bit words. As a result, at the instant the AC signal 988 in FIG. 24 crosses zero in the positive-going direction, the AND gate 666 in FIG. 19A will have a signal applied to the upper input thereof by the flip-flop 648; and the Hue Zero Crossing Detector block 302 and the Monostable Multivibrator block 306 of FIG. 12 will apply a signal to the lower input of that AND gate; and, thereupon, that AND gate will apply a signal to the integrator 686 of the Integrators block 313 in FIG. 19A.

The word comparators 596 and 587 will subsequently respond to the 7-bit word from the counter 246, and that 7-bit word will cause those word comparators to reset the flip-flop 648, to set and reset the flip-flop 650 and to set the flip-flop 632. This means that the AND gates 668 and 651 will have signals applied to the upper inputs thereof by the flip-flops 650 and 632, respectively; but the Hue Zero Crossing Detector block 302 and the Monostable Multivibrator block 306 of FIG. 12 will not apply signals to the lower inputs of those AND gates and hence those AND gates will not apply signals to the integrators 688 and 670, respectively, of the Integrators block 313 in FIG. 19A.

The color identification unit will actuate the AND gate 666 in FIG. 19A every 5 microseconds while the spot 90 of light is on the yellow area of the document 53; and that AND gate will apply a signal to the integrator 686 every 5 microseconds. Very quickly, that integrator will develop a signal and will apply that signal to the amplitude comparator 714 and also to the Comparator Reference Selector block 315 of FIG. 19A. Since the amplitude of the signal from the integrator 686 exceeds all other inputs to the OR gate 299, the output of integrator 686 is passed to the lower input of the differential am-

plifier 292, and will cause that differential amplifier to apply a signal—which is slightly less than the output of the integrator 686—to the lower input of the amplitude comparator 714, and that amplitude comparator will then supply a signal to the AND gate 768, and also to the Validity Comparator block 322; and, if only one amplitude comparator supplies a signal to the Validity Comparator block 322, the amplifier 718 will apply a signal to the lower input of AND gate 768, and that AND gate will apply a signal to the lower input of AND gate 904 in FIG. 21.

During the 300° when the Hue Position Control 238 was receiving 7-bit words from the counter 246 and from the card reader 232, the Hue Position Control 240 also was receiving 7-bit words from that counter and from that card reader; and the Latitude Control Subcircuits block 332 in FIG. 13 was receiving five digital signals from that card reader and was applying five analogue signals to the comparators of the Latitude Comparator block 330. By the time the AC signal 988 of FIG. 24 crossed zero in the positive-going direction at 300°, the word comparator 243 had responded to the 7-bit words from the counter 246 and from the card reader 232 to reset the flip-flop 772, and the word comparators 243, 245, 247 and 248 had responded to the 7-bit words from the counter 246 and from the card reader 232 to set and reset the flip-flops 774, 776 and 778 and to set the flip-flop 780. This means that the flip-flop 780 was applying a signal to the upper input of the AND gate 790 at the instant the Hue Zero Crossing Detector block 302 and the Monostable Multivibrator block 306 of FIG. 12 applied a signal to the upper input of that AND gate; and hence that AND gate applied a signal to the "set" input of the integrator 800. The counter 246 will subsequently supply a 7-bit word to the word comparator 241 which will cause that word comparator to reset the flip-flop 780 and to set the flip-flop 772. This means that the AND gate 782 will have a signal applied to the upper input thereof; but the Hue Zero Crossing Detector block 302 and the Monostable Multivibrator block 306 of FIG. 12 will not apply a signal to the lower input of that AND gate, and hence that AND gate will not apply a signal to the integrator 792 of the Integrators block 608 in FIG. 19B.

The color identification unit will actuate the AND gate 790 in FIG. 19B every 5 microseconds while the spot 90 of light is on the yellow area of the document 53; and that AND gate will apply a signal to the integrator 800 every 5 microseconds. Very quickly, that integrator will develop a signal and will apply that signal to the amplitude comparator 816 and to the Comparator Reference Selector block 612 in FIG. 19B. Since the amplitude of the signal from the integrator 800 exceeds all other inputs to the OR gate 802, the output of the integrator 800 is passed to the lower input of the differential amplifier 804, and will cause that differential amplifier to apply a signal—which is slightly less than the output of the integrator 800—to the lower input of the amplitude comparator 816, and that amplitude comparator will then supply a signal to the AND gate 852, and also to the Validity Comparator block 626; and, if only one amplitude comparator supplies a signal to the Validity Comparator block 626, the amplifier 718 will apply a signal to the lower input of the AND gate 852, and that AND gate will apply a signal to the upper input of AND gate 894 in FIG. 21.

The Color Contrast And Latitude Computer block 366 in FIG. 4 receives amplified signals from the Signal Conditioning And Filtering block 119 via conductors 134 and 374 and via conductors 168 and 372; and it develops a signal equal to the square of the cosine of the latitude angle of the pigment "seen" by the light sensors 102 and 104; and it applies that signal to the upper input of comparator 342 and to the lower inputs of comparators 333, 334, 335, 336 and 338 in FIG. 13. Because the pigment "seen" by the light sensors 102 and 104 is yellow—and thus is a pigment which has a high lightness and saturation value, and the latitude angle 42 in the color solid 20 of FIG. 1 will be large—the value of the square of the cosine of the latitude angle corresponding to that pigment will be too small to "match" the latitude level signals supplied to the

upper inputs of the comparators 333, 334, 335, 336 and 338 by the Latitude Control Subcircuits block 332. Also, the value of the square of the cosine of the latitude angle corresponding to that pigment will be too small to "match" the black latitude level applied to the comparator 342 by the movable contact of the potentiometer 344.

Whenever any of the comparators 333, 334, 335, 336 and 338 fails to receive a signal at the lower input thereof, which equals or exceeds the latitude level signal supplied to the upper input thereof by the Latitude Control Subcircuits block 332, that comparator will not develop a signal at the output thereof. When the comparator 342 fails to receive a signal at the upper input thereof, which equals or exceeds the black latitude level applied to the lower input thereof by the movable contact of the potentiometer 344, that comparator will not develop a signal at the lower output thereof but will develop a signal at the upper output thereof; and the signal at that upper output will be applied to the lower inputs of all of the AND gates 890, 891, 892, 893 and 894. While the AND gate 894 will have signals at the upper and lower inputs thereof, that AND gate will not have a signal at the middle input thereof; and hence that AND gate will not develop a signal at the output thereof. The other AND gates 890, 891, 892 and 893 also will not develop signals at the outputs thereof, and hence no signal will be applied to any of the inputs of the NOR gate 352; and, as a result, that NOR gate will develop an output signal and will apply it to the upper inputs of all of the AND gates 896, 897, 898, 899, 900, 901, 902, 903, 904 and 905. This means that the AND gate 904 in FIG. 21 will have a signal at the upper input as well as at the lower input thereof, and that AND gate will respond to those signals to develop a signal at the output thereof and will apply that signal to Color Number Code Matrix block 564 in FIG. 14 via conductor 946; and that Color Number Code Matrix then will supply an appropriate signal to the Computer Buffer block 570 via one of the conductors of cable 573.

The $2C^2$ and $2(C_1)^2$ signals which will be developed by the Color Contrast And Latitude Computer block 366—as the light sensors 102 and 104 "see" the yellow area on the document 53—will be applied to the junctions 468 and 466 in FIG. 15; and the sum amplifiers 487, 507, 537 and 545, the OR gates 514, 518, 522 and 546, and the gate generators 524 and 548 of FIG. 15 will cause the AND gate 529 to develop a signal at the output thereof and to apply that signal to the Computer Buffer block 570. Simultaneously, that Computer Buffer block will receive a signal from the Drum And Scanner Drive block 115. That Computer Buffer block will respond to those three signals to apply an appropriate signal to the Buffer And Data Record Control block 580 and thus to the Recorder block 582.

The positive-going zero crossing of the AC signal 988 in FIG. 24 thus coacted with the flip-flop 648, the AND gate 666, the integrator 686, the Comparator Reference Selector block 315, the amplitude comparator 714, the Validity Comparator block 322, and the AND gate 768 of FIG. 19A to supply a hue-identifying signal to the Digital Code Generator block 556, and also coacted with the flip-flop 780, the AND gate 790, the integrator 800, the Comparator Reference Selector block 612, the amplitude comparator 816, the Validity Comparator block 626, and the AND gate 852 of FIG. 19B to supply a hue-identifying signal to that Digital Code Generator block. However, because the pigment "seen" by the light sensors 102 and 104 was a pigment which has high lightness and saturation values, the angle 42 in the color solid 20 of FIG. 1 was large and the value of the square of the cosine of the latitude angle corresponding to that pigment was so small that none of the comparators 333, 334, 335, 336 and 338 developed a signal at the output thereof and the comparator 342 did not develop a signal at the lower output thereof. The Latitude Comparator block 330 of FIG. 4 thus responded to the square of the cosine of the latitude angle of the pigment "seen" by the light sensors 102 and 104 to cause the Digital Code Generator block 556 to supply a signal to the Buffer

And Data Record Control block 580, and thus to the Recorder block 582, which showed that it was a yellow pigment that caused the light sensors 102 and 104 to produce the AC signal 988 in FIG. 24.

It should be apparent from the foregoing that the color identification unit varies the intensities of the light sources 64 and 66 to keep the light reflected from the base material of the document 53 essentially white, develops a signal which is a measure of the contrast vector of the pigment "seen" by the light sensors 102 and 104, develops a signal which is a measure of the longitude angle of the pigment "seen" by those sensors, develops a signal which is a measure of the square of the cosine of the latitude angle, and then uses the contrast vector signal and the longitude angle signal and the signal which is a measure of the square of the cosine of the latitude angle to definitely identify the pigment "seen" by the light sensors 102 and 104. In addition, it should be apparent that the color identification unit supplies information to the Digital Code Generator block 556, and via the Buffer And Data Record Control block 580 to the Recorder block 582, which correlates the identity of the pigment "seen" by the light sensors 102 and 104 with a fixed point on the surface of the document 53. Further, it should be apparent that the color identification unit supplies a signal to the Digital Code Generator block 556, and via the Buffer And Data Record Control block 580 to the Recorder block 582, which indicates whether the light sensors 102 and 104 have been "seeing" a line or a colored area on the document 53.

PROGRAMMING OF COLOR IDENTIFICATION UNIT

To program the color identification unit provided by the present invention, the operator will carefully inspect the document 53 which is to be mounted on the drum 52 of that color identification unit. That inspection should include a determination of the total number of different pigments used to form colored areas on the document, should include a determination of the longitude and latitude values of those pigments, and should include a determination of the width of the narrowest line on that document. These determinations can be made, in part, by visual inspection, and, in part, by actual measurement by using the color identification unit itself. The procedure for using the color identification unit for making these determinations requires that the color identification unit is first "set up" with a few initial conditions.

Ordinarily, the operator of the color identification unit will select or punch a card for the card reader 232 which will cause the Phase Control Circuit block 234 of FIG. 11 to phase-displace the waveforms—corresponding to the red, blue and green light forming the spot 90 at the surface of the document 53—120°; with the waveform for the blue light lagging the waveform for the red light by 120° and with the waveform for the green light leading the waveform for the red light by 120°. However, in certain instances, some pigments on a document may require the color identification unit to exhibit a high sensitivity to hue differences in specific angular areas on the polar coordinate graphs of FIGS. 29 and 31; and, in those instances, the card for the card reader 232 should be selected or punched to supply signals to the Phase Control Circuit block 234 which would enable that Phase Control Circuit block to change the phase angles between the waveforms corresponding to the red, blue and green light. For example, if a document had several different pigments in the angular area between 225° and 318° on the polar coordinate graph of FIG. 29, the operator of the color identification unit should select or punch a card for the card reader 232 which would cause the Phase Control Circuit block 234 to decrease the angular displacement between the waveforms corresponding to the red light and the blue light, and to increase the angular displacement between the waveforms corresponding to the blue light and the green light. The resulting decreased angular displacement between the waveforms corresponding to the red light and the green light would enable the color identification unit

to have a higher sensitivity to differences in hue in the angular area between the angle of 225° and the angle of 318° in FIG. 29. On the other hand, if the document had a large number of different pigments in the angular area between an angle of 33° and an angle of 158°, the operator of the color identification unit should select or punch a card for the card reader 232 which would enable the Phase Control Circuit block 234 to decrease the angular displacement between the waveforms corresponding to red light and blue light, to increase the angular displacement between the waveforms corresponding to the red light and green light, and to increase the angular displacement between the waveforms corresponding to blue light and green light.

The operator of the color identification unit should make sure that the diameter of the aperture 98 in the aperture plate 96 is smaller than the width of the narrowest line on the document 53. If that diameter is not smaller than the width of that line, the operator should replace the aperture plate 96 with another aperture plate that has a smaller-diameter aperture 98.

The operator will shift the scanner 60 until the spot 90 of light is on the base material of the document 53, and then he will press the pushbutton switch 528 in FIG. 15. The resulting signal from the upper output of gate generator 524 will cause the gates 232 and 286 in FIG. 9 to connect the Phase Detector block 276 to the integrators 288 and 290, and will thereby enable the lamp drivers 296 and 298 to set the intensities of the light sources 64 and 66 so the light reflected from that base material will be essentially white. Thereafter, the Hue Balance Control block 274 will provide any adjustments in the intensities of the light from those two light sources to keep the light reflected from the base material of the document essentially white—irrespective of changes in line voltage, of changes in the efficiency of any of the three light sources, and of variations in the reflectivity of that base material. The color identification unit is now "set up" to measure the longitude and latitude of colors on the document 53.

The operator will shift the scanner 60 until the spot 90 of light is on an area which is of the color which he desires to measure. Using conventional measuring instruments and techniques, the time interval between the reset of the counter 246 and the positive-going zero-crossing pulse from the multivibrator 306 is measured. This time interval measurement provides a measurement of longitude angle of that pigment through the linear relationship of 5 microseconds equaling 360°. A time measuring instrument such as an oscilloscope, can be provided as "builtin" equipment; however, more practically, conveniently located signal terminals would provide sufficient convenience for use with portable test equipment. A special "builtin" measurement circuit could be provided, such as a "hold register" which would sample, store, and display the count which is in the counter 246 at the time that the positive-going zero-crossing pulse occurs. Any other satisfactory method of measuring the time interval between the counter 246 reset and the positive-going zero-crossing pulse should be apparent to those skilled in the art.

The longitude angle 32 of a pigment may be determined by the measurement of the square of the cosine of the latitude signal which is computed by the Color Contrast And Longitude Computer 366 and which appears on the conductor 456. An external meter may be used, or the color identification unit may be provided with a "builtin" meter to permit that measurement to be made. Other methods of measuring the square of the cosine of the latitude signal should be apparent to those skilled in the art.

For purposes of illustration, it will be assumed that a total of 10 colored pigments were used in printing or drawing the document 53, and that the said pigments are: red, lilac, purple, blue, cyan, green, olive, yellow, orange and brown. The longitude measurement of these pigments will be found to be: red, 11°; lilac, 90°; purple, 90°; blue, 159°; cyan, 202°; green, 245°; olive, 266°; yellow, 298°; orange 340°; brown, 341°.

The provision of the two hue position hue blocks 238 and 240 in FIG. 11 is important, because certain different pigments will have similar longitude angles. The characteristics which provide easy visual discrimination of two such pigments is that one color will have high lightness and saturation values whereas the other color of similar hue will have low lightness and saturation values. The discrimination of these similar hues is provided in the color identification unit through the measurement of the latitude angle. For example, as shown by the following chart, the hue angles—referred to as the longitude angles—of several pigments have similar values, whereas the latitude angles of those similar pigments are distinctly different:

Pigment	Longitude angle, degrees	(Cosine) ² of latitude angle
Brown.....	341	.94
Orange.....	340	.74
Red.....	11	.66
Purple.....	90	.97
Lilac.....	90	.68
Olive.....	266	.91
Green.....	245	.79
Yellow.....	298	.29

In selecting or punching the card for the card reader 232 in FIG. 11, the operator of the color identification unit must consider the angular placements as well as the angular dimensions of the various "angle slots"; because both the angular placement and the angular dimension of an "angle slot" are important in sensing the pigment used in a given colored area. For example, if a yellow pigment absorbed all blue light directed toward it and reflected all red and green light directed toward it, as indicated by FIG. 24, the light reflected from that pigment would cause the light sensors 102 and 104 to develop an AC signal with a positive-going zero-crossing at about 300°; and hence the "angle slot" for that pigment would have to have an angular placement and an angular dimension which would enable it to include the angle of 300°. As shown particularly by FIG. 26, the light reflected from an orange pigment will cause the light sensors 102 and 104 to develop an AC signal with a positive-going zero-crossing at about 340°; and hence the "angle slot" for an orange pigment must have an angular placement and an angular dimension which would enable it to include the angle of 340°.

If all of the pigments used in forming the yellow areas on a document 53 had exactly the same values of hue, if all of the pigments used in forming the orange areas on that document had exactly the same values of hue, and if all of the pigments used in forming the green areas on that document had exactly the same values of hue, it would be possible to provide very narrow "angle slots" for the yellow pigments. Similarly, if all of the pigments used in forming each differently-colored area on the document 53 had exactly the same values of hue, it would be possible to provide very narrow "angle slots" for those various pigments. However, the pigments used in preparing colored areas on a document can vary in hue values at the time they are applied to the document; and, depending upon the amount of handling and exposure to light and air experienced by the various colored areas on the document, some of those colored areas can experience appreciable changes in hue values. For example, if one portion of a document has been exposed to bright light and air for an appreciable period of time, the hue of the colored area on that portion can fade and be appreciably different from the hue of other similarly-colored areas on that document. Consequently, it is desirable to make the "angle slot" for each individually-different pigment wide enough to accommodate the variations in hue value which that pigment can be expected to experience.

As indicated by a comparison of FIGS. 26 and 27, the light sensors 102 and 104 will respond to light reflected from an

orange area to provide an AC signal with a positive-going zero-crossing of about 340° , and will respond to light reflected from an area which is one-half white and one-half orange—as is the case where the spots 960 and/or 962 of FIG. 33 are just crossing from the base material into an orange colored area, or where the area is incompletely pigmented and the base material in the interstices comprises one-half the area of the spots 960 and/or 962—to provide an AC component with the same positive-going zero-crossing. The amplitude of the waveform of the AC component in FIG. 27 is appreciably smaller than the amplitude of the waveform of the AC component in FIG. 26, because the presence of the light reflected from the white area reduces the saturation of the pigment “seen” by the light sensors 102 and 104 and because amplitude is a measure of saturation; but, importantly, the angular positions of the positive-going zero-crossings in FIGS. 26 and 27 are the same. As a result, an “angle slot” which includes an angle of 340° and which has an angular width that enables it to extend several degrees on opposite sides of the angle of 340° will encompass all of the positive-going zero-crossings of AC signals which the light sensors 102 and 104 will develop when they “see” orange areas on a document—whether those orange areas include different percentages of white and whether those areas have experienced fading or other light-induced degradation.

Similarly, the selection of an angular dimension and angular placement for an “angle slot” which enables that “angle slot” to include an angle of 11° and which extends several degrees on opposite sides of that angle will enable that “angle slot” to encompass all of the positive-going zero-crossings of AC signals which are developed by the light sensors 102 and 104 as those light sensors “see” red areas on a document—whether those red areas include white areas or have experienced fading or other light-induced degradation. As indicated by FIG. 29, “angle slots” that respectively include a 90° angle, an angle of 159° , an angle to 202° , and an angle of 245° , and that extend several degrees on opposite sides of those angles, will, respectively, encompass the positive-going zero-crossings of the AC signals developed by the light sensors 102 and 104 when those light sensors “see” lilac areas, blue areas, cyan areas and green areas on documents—whether those areas include white areas or have experienced fading or other light-induced degradation.

The blue, cyan, green, lilac, orange, red and yellow pigments are relatively high lightness and saturation colors, and hence the latitude angle 42 in the color solid 20 of FIG. 1 is large; and a card will be selected or punched for the card reader 232 of FIG. 11 which will coact with the Hue Position Control block 238 to provide “angle slots” for those seven pigments. For example, as shown by FIG. 29, an “angle slot” of 36° can be provided for the red pigment, an “angle slot” of 42° can be provided for the lilac pigment, an “angle slot” of 42° can be provided for the blue pigment, an “angle slot” of 45° can be provided for the cyan pigment, an “angle slot” of 48° can be provided for the green pigment, an “angle slot” of 45° can be provided for the yellow pigment, and an “angle slot” of 39° can be provided for the orange pigment. Also as indicated by FIG. 29, the “angle slot” for the red pigment is spaced from the “angle slot” for the lilac pigment by two “angle slots” which will not be used to develop signals; and another unused “angle slot” is provided between the “angle slots” for the lilac and blue pigments. Those “angle slots” are not used because colors which would correspond to those “angle slots” were not used in preparing the document 53. The unused “angle slots” can be given various widths; but, in FIG. 29, each of the two “angle slots” between the red and lilac “angle slots” has a width of 18° , and the “angle slot” between the lilac and blue “angle slots” has a width of 27° .

The brown, olive and purple pigments have relatively low lightness and saturation values, and hence the latitude angle 42 in the color solid 20 of FIG. 1 is small; and the card, which will be used in the card reader 232 of FIG. 11, will be selected or will be punched to coact with the Hue Position Control

block 240 to provide “angle slots” for those three pigments. As indicated particularly by FIG. 31, an “angle slot” of 87° is provided for the brown pigment, an “angle slot” of 120° is provided for the purple pigment, and an “angle slot” of 93° is provided for the olive pigment. Two unused “angle slots” are provided between the purple and olive “angle slots” because colors which would correspond to those “angle slots” were not used in preparing the document 53. Each of the unused “angle slots” has a width of 30° .

The polar coordinate graphs of FIGS. 29 and 31 show that the “angle slot” for brown is wider than and encompasses the “angle slot” for orange, and thus indicates that for every shade of orange there is a shade of brown which has the exact same longitude angle. Similarly, the polar coordinate graphs of FIGS. 29 and 31 show that the “angle slot” for purple is wider than and encompasses the “angle slot” for lilac, and thus indicates that for every shade of lilac there is a shade of purple which has the exact same longitude angle. The polar coordinate graphs of FIGS. 29 and 31 also show that the “angle slot” for olive is wider than and encompasses the “angle slot” for green, and thus indicates that for every shade of green there is a shade of olive which has the exact same longitude angle. The polar coordinate graphs of FIGS. 29 and 31 further show that the “angle slot” for olive encompasses most of the “angle slot” for yellow, and thus indicate that for most shades of yellow there is a shade of olive which has the exact same longitude angle. This means that if just the Hue Position Control block 238 was used in FIG. 11, and if the card in the card reader had to coact with that Hue Position Control block to provide “angle slots” for orange and brown pigments, the color identification unit could not precisely determine whether the positive-going zero crossing of the AC signal developed by the light sensors 102 and 104 was due to an orange pigment or a brown pigment. Similarly, if the card of the card reader 232 had to coact with the Hue Position Control block 238 to provide “angle slots” for lilac pigments and purple pigments, the color identification unit could not precisely determine whether the positive-going zero crossing of the AC signal developed by the light sensors 102 and 104 was due to a lilac pigment or a purple pigment. Further, if the card of the card reader 232 had to coact with the Hue Position Control block 238 to provide “angle slots” for green and olive pigments and for some yellow and olive pigments, the color identification unit could not precisely determine which pigment was responsible for the positive-going zero crossing of the AC signal developed by the light sensors 102 and 104.

The use of the Hue Position Control block 240 in addition to the Hue Position Control block 238, plus the use of the Latitude Comparator block 330 and of the Color Contrast And Latitude Computer block 366 and of the Digital Code Generator block 556, enables the color identification unit of the present invention to distinguish between the positive-going zero crossings of the AC signal developed by the light sensors 102 and 104 as they “see” brown and orange areas, lilac and purple areas, green and olive areas, and yellow and olive areas; because the Color Contrast And Latitude Computer block 366 determines the square of the cosine of the latitude angle of the various pigments “seen” by the light sensors 102 and 104. The latitude angle of a pigment is the angle subtended by the lightness difference vector 40 and the contrast vector 38 for that pigment in the color solid 20 of FIG. 1, and the numeral 42 denotes the latitude angle of the pigment whose position within that color solid is indicated by the numeral 30; and the squares of the cosines of the latitude angles of two pigments, which can easily be seen to be different pigments although they have similar or even identical longitude angles, will be sufficiently different to enable those pigments to be distinguished. The cosine of a latitude angle is the ratio of the lightness difference vector of a pigment to the contrast vector of that pigment; and the value of that cosine can be used in determining whether that pigment has a high lightness and saturation or a low lightness and saturation.

As indicated by a comparison of FIGS. 26 and 27, the amplitude of the waveform of the AC component in FIG. 27 is appreciably smaller than the amplitude of the waveform of the AC component in FIG. 26, because the presence of the light reflected from the white area reduces the saturation of the pigment "seen" by the light sensors 102 and 104 and because amplitude is a measure of saturation; but, importantly, the lightness difference value of the waveform in FIG. 27 also is smaller than the lightness difference value in FIG. 26, and the ratio of saturation value to lightness value in FIG. 26 is the same as the ratio of saturation value to lightness value in FIG. 27. As a result, the square of the cosine of the latitude angle, which is computed by the Color Contrast And Latitude Computed block 366, will be the same whether those orange pigmented areas include different percentages of white. Similarly, the square of the cosine of the latitude angle which is computed as a result of a red, lilac, purple, blue, cyan, green, olive, yellow, orange or brown color will be consistent whether areas pigmented in that color contain varying percentages of the white base material.

A card will be selected or punched for the card reader 232 of FIG. 11 which will coact with the Latitude Control Subcircuits block 332 of FIG. 13 to provide reference voltages to the comparators 333, 334, 335, 336 and 338, and thus will provide a color determination based on the square of the cosine latitude signal appearing on conductor 456. For example, a brown pigment will cause a signal to appear at the output of the AND gate 844 in the AND Gates block 622 of FIG. 19B; and that signal is applied through cable 307 to the AND gate 890 in the AND Gates block 561 of FIG. 21. An orange pigment also will cause a signal to appear at the output of AND gate 844, and that signal also will be applied to the AND gate 890. Most red pigments also will cause a signal to appear at the output of AND gate 844, and that signal also will be applied to the AND gate 890. The brown pigment will cause a signal to appear at the output of the AND gate 770 in the AND Gates block 320 of FIG. 19A, and that signal will be applied through cable 305 to the AND gate 905 in the AND Gates block 558 of FIG. 21. An orange pigment also will cause a signal to appear at the output of the AND gate 770, and that signal will cause a signal to appear at the output of the AND gate 752 of the AND Gates block 320 of FIG. 19A, and that signal will be applied to the AND gate 896 of the AND Gates block 558 of FIG. 21.

The operator will select or punch a card which will cause a voltage to be generated by the Latitude Control Subcircuits block 332 of FIG. 13; and that voltage will correspond to a numerical value of eighty-four hundredths, and it will be applied to the topmost input of comparator 333 of FIG. 13. The brown pigment will cause a square of the cosine of latitude signal which corresponds to a numerical value of ninety-four hundredths to appear on the conductor 456 and thus to be applied to the lowermost input of comparator 333. Because the topmost input to comparator 333 is of lower numerical value than the bottom most input to that comparator, that comparator will cause a signal to appear at its output; and that signal will be applied through cable 337 to the AND gate 890 of AND Gates block 561 of FIG. 21. The comparator 342 will have a numerical value greater than ninety-seven hundredths at its lowermost input and hence that comparator will cause a signal to appear on conductor 339 but will not cause a signal to appear on conductor 349; and the signal on conductor 339 will be connected to the AND gate 890 of the AND Gates block 561 of FIG. 21. A brown pigment will thus cause three signals to appear at the AND gate 890, and that AND gate will cause a signal to appear on the conductor 918; and the NOR gate 352 will respond to the latter signal to apply no signal to the upper inputs of the AND gates in AND Gates block 558.

An orange pigment or red pigment will cause a signal of numerical value, seventy-four hundredths or sixty-six hundredths, respectively, to appear on conductor 456. Since those signals have lower values than the signal appearing at the uppermost input of comparator 333, no signal will be generated

at the output of that comparator; and hence AND gate 890 will become inactive, no signal will appear on conductor 918 and NOR gate 352 will apply a signal to the upper inputs of the AND gates in the AND Gates block 558—thereby causing AND gate 896 to become active in the presence of a red pigment and causing AND gate 905 to become active in the presence of an orange pigment. Similarly, a card will be selected or punched to supply signals to comparators 334 and 338 which will provide discrimination of the purple and lilac pigments and of the olive and green pigments or the olive and yellow pigments, respectively.

The presence of a black line or area on the document 53 will cause a signal with a numerical value of one to appear on conductor 456. The operator will adjust the movable contact of potentiometer 344 to develop a signal having a numerical value less than one but greater than the greatest signal provided by the Latitude Control Subcircuits block 332. The comparator 342 will thus provide a signal on conductor 339 and no signal on conductor 349 unless a black pigment is present; but when such a pigment is present, no signal will appear on conductor 339 and a signal will appear on conductor 349.

With no signal on conductor 339, the AND gates in AND Gates block 561 of FIG. 21 will be inactive. The signal on conductor 349 will be applied to NOR gate 352; and that NOR gate will remove the signals from the upper inputs of the AND gates in AND Gates block 558 thereby causing those AND gates to become inactive. The color identification unit is thus programmed; and a signal will appear at only one of the 16 conductors 930, 932, 934, 936, 938, 940, 942, 944, 946, 948, 926, 924, 922, 920, 918 and 349—that signal corresponding to the pigment which falls within the latitude and longitude parameters programmed by the card reader 232.

DETAILED DESCRIPTION OF OPERATION OF COLOR IDENTIFICATION UNIT

A. Operation of Phase Control Circuit Block

The card reader 232 of FIG. 11 will respond to a card therein to supply six 7-bit words to the Phase Control Circuit block 234; and the counter 246 will supply a 7-bit word to that block. Each of the 7-bit words from the card reader 232 will be fixed and unchanging and will be supplied continuously to the Phase Control Circuit block; but the 7-bit word from the counter 246 will continually change at the rate of 24 megacycles per second. Because that counter resets itself every time it counts up to 120, it cycles at a frequency of 200 kilocycles per second; and each bit represents 3° of a cycle of that counter. For purposes of illustration it will be assumed that the 7-bit word supplied by the cable 173 in FIG. 18 is 0000000, that the 7-bit word supplied by the cable 171 is 0111100, that the 7-bit word supplied by the cable 169 is 0101000, that the 7-bit word supplied by the cable 167 is 1100100, that the 7-bit word supplied by the cable 165 is 1010000, and that the 7-bit word supplied by the cable 163 is 0010100. This means that the Word Comparator 870 in FIG. 18 will act, whenever the count from the counter 246 is zero, to apply a "set" signal to the flip-flop 882, and thereby cause that flip-flop to initiate the square wave 950 in FIG. 22. The word comparator 874 will act, whenever the count from the counter 246 is 40, to apply a "set" signal to the flip-flop 884, and thereby cause that flip-flop to initiate the square wave 952 in FIG. 22. The word comparator 872 will act, whenever the count from the counter 246 is 60, to apply a "reset" signal to the flip-flop 882, and thereby cause the flip-flop to terminate the square wave 950. The word comparator 878 will act, whenever the count from the counter 246 is 80 to apply a "set" signal to the flip-flop 886, and thereby cause that flip-flop to initiate the square wave 954 in FIG. 22. The Word Comparator 876 will act, whenever the count from the counter 246 is 100, to apply a "reset" signal to the flip-flop 884, and thereby cause that flip-flop to terminate the square wave 952. The word comparator 870 will act, when the counter 246 reset to again make the count therefrom zero,

to apply a "set" signal to the flip-flop 882, and thereby cause that flip-flop to initiate the square wave 956 in FIG. 22. The Word Comparator 880 will act, whenever the count from the counter 246 is 20, to apply a "reset" signal to the flip-flop 886 and thereby cause that flip-flop to terminate the square wave 954. It will be noted that each square wave has a duration of 180°, and that the leading edge of square wave 952 lags the leading edge of wave 950 by 120° while the leading edge of square wave 954 leads the leading edge of square wave 956 by 120°.

The word comparators of the Phase Control Circuits block 234 will continue to respond to the fixed and unchanged 7-bit words from the card reader 232 and to the constantly-changing 7-bit word from the counter 246 to develop square waves that have durations of 180° and that have the leading edges thereof displaced by 120°. Those square waves will be converted to sine waves by the Carrier Generator block of FIG. 4; and those sine waves will be supplied to the Light Modulators block 110 and to the phase sensitive detectors 269 and 278 of the Phase Detector block 276 of FIG. 9. The modulators in the Light Modulator block 110 will respond to those sine waves to modulate the intensities of the light from the filters 70, 72 and 74 of FIG. 3 to produce the light waveforms 326, 327 and 328 shown in FIG. 7. The waveform 326 will represent the modulated red light, the waveform 327 will represent the modulated blue light, and the waveform 328 will represent the modulated green light. When the waveform 326 is at its maximum amplitude, the amplitudes of the waveforms 327 and 328 will be below the average values of those waveforms. Similarly, when the waveform 327 is at its maximum amplitude, the amplitudes of the waveforms 326 and 328 will be below the average values of these waveforms; and when the waveform 328 is at its maximum amplitude, the amplitudes of the waveforms 326 and 327 will be below the average values of those waveforms. This means that although the spot 90 of light will be essentially white, it will consist of a mixture of red, blue and green light wherein red light will predominate for 120°, blue light will predominate for the next 120°, and green light will predominate for the last 120° of each cycle of the counter 246.

If it should ever become desirable to change the duration of the time interval during which the red light or the blue light or the green light used to form the spot 90 of light in FIG. 3 is dominant, that change can easily be effected by using an appropriately punched card in the card reader 232. Similarly, if it should ever become desirable to change the phase angles between the modulated red light, the modulated blue light, and the modulated green light, that change can easily be effected by inserting an appropriately punched card in the card reader 232. As a result, the color identification unit of the present invention facilitates ready and accurate selection of the duration and phase displacement of the modulated red light, the modulated blue light, and the modulated green light.

B. Operation of Signal Conditioning And Filtering Block And of Gain Control Circuits Block

The light sensors 102 and 104 are photomultiplier tubes, and such tubes act as current sources—causing current to flow under steady-state light conditions. The current developed by the light sensor 102 will flow via conductor 125, junction 124, resistor 200, and junction 204 to the voltage reference 206; and the resulting voltage drop across that resistor will buck the voltage from that voltage reference—tending to make the voltage at the junction 124, and thus at the input of amplifier 126, zero whenever the light sensor 102 "sees" the base material of the document 53. Similarly, the current developed by the light sensor 104 will flow via conductor 127, junctions 159 and 160, resistor 202, and junction 204 to the voltage reference 206; and the resulting voltage drop across that resistor will buck the voltage from that voltage reference—tending to make the voltage at the junction 159, and thus at the input of amplifier 158, zero whenever the light sensor 104 "sees" the base material of the document 53. Because the voltages at the inputs of the amplifiers 126 and 158 will be zero,

whenever the light sensors 102 and 104 "see" the base material of the document 53, the voltages at the outputs of those amplifiers also will be zero.

Photomultiplier tubes are inherently unstable; and hence the gain of either or both of the light sensors 102 and 104 could vary during the scanning of a document 53. Any such variations in gain would tend to affect the operation of the color identification unit in an adverse manner; and the Gain Control Circuits block 117 of FIG. 4 holds the total gains of the light sensors 102 and 104 substantially constant by varying the high voltages that are applied to the dynode circuits of those light sensors. Specifically, the movable contact of the adjustable resistor 122 is automatically shifted to adjust the total value of the voltages available to the dynode circuits of the light sensors 102 and 104; and the movable contact of the potentiometer 120 is automatically shifted to vary the proportions of that total value which are supplied to the dynode circuit of those light sensors. In this way, the gains of the light sensors 102 and 104 are balanced relative to each other, and the total gains of those light sensors are kept substantially constant.

Each of the light sensors 102 and 104 will develop an electric signal which has a DC component and an AC component; and the DC and AC components of the signal developed by the light sensor 102 will be amplified by the wide band amplifier 126. The amplified AC and DC components of the signal developed by the light sensor 102 will be applied to the Hue Comparator block 300 and to the Color Contrast And Latitude Computer block 366 of FIG. 4, and also will be applied to the operational amplifier 147 which acts as a low pass filter; and that operational amplifier will pass only DC signals and signals which have frequencies below about 1 cycle per second. The DC and AC components of the signal developed by the light sensor 104 will be amplified by the wide band amplifier 158; and the resulting amplified DC and AC components will be applied to the Hue Comparator block 300 and to the Color Contrast And Latitude Computer block 366 of FIG. 4, and also will be applied to the operational amplifier 181 which acts as a low pass filter. That operational amplifier will pass only DC signals and signals having frequencies below about 1 cycle per second. The resulting essentially DC signals at the outputs of the operational amplifiers 147 and 181 will be applied to the input of the sum amplifier 157, and also will be applied to the inputs of the difference amplifier 195. Sum amplifier 157 will sum the essentially DC signals applied to the input thereof and will develop an output voltage which it will apply to the input of the driver amplifier 214; and, if that output voltage is at a predetermined level, that driver amplifier will not actuate the servomotor 210, and hence the position of the movable contact of the adjustable resistor 122 will remain unchanged. However, if the voltage applied to the input of the driver amplifier 214 exceeds the predetermined level, that driver amplifier will actuate the servomotor 210 and cause it to shift the movable contact of the adjustable resistor 122 to the right and thereby decrease the value of the voltage which the Power Supply block 118 supplies to the movable contact of the potentiometer 120, and thus to the dynode circuits of the light sensors 102 and 104. On the other hand, if the voltage applied to the input of the driver amplifier 214 is below the said predetermined level, that driver amplifier will actuate the servomotor 210 and cause it to shift the movable contact of the potentiometer 122 to the left and thereby increase the value of the voltage which the Power Supply block 118 supplies to the movable contact of the potentiometer 120, and thus to the dynode circuits of the light sensors 102 and 104. In this way, the circuits shown in FIG. 8 will automatically vary the total value of the voltage applied to the light sensors 102 and 104, and thus will automatically vary the total gains of those light sensors to maintain a substantially constant voltage at the output of the sum amplifier 157.

The difference amplifier 195 will respond to the essentially DC signals applied to the upper and lower inputs thereof to develop a signal at the output thereof in the event those essen-

tially DC signals are not equal. The driver amplifier 212 will respond to any signal at the output of the difference amplifier 195 to apply a signal to the servomotor 208. Specifically, if a signal at the output of difference amplifier 195 indicates that the gain of the light sensor 102 is greater than the gain of the light sensor 104, the driver amplifier 212 will actuate the servomotor 208 and cause it to shift the movable contact of the potentiometer 120 to the left, thereby increasing the gain of the light sensor 104 and decreasing the gain of the light sensor 102 until those gains are substantially equal. Conversely, if the signal at the output of difference amplifier 195 indicates that the gain of the light sensor 104 is greater than the gain of the light sensor 102, the driver amplifier 212 will actuate the servomotor 208 and cause it to shift the movable contact of the potentiometer 120 to the right, thereby increasing the gain of the light sensor 102 and decreasing the gain of the light sensor 104 until those gains are substantially equal.

In this way, the circuits shown in FIG. 8 will vary the gain of each of the light sensors 102 and 104 to maintain those gains substantially equal; and also will vary those gains so the voltages at the junctions 130 and 166 will be essentially zero when both of those light sensors "see" the base material of the document 53. Because the operational amplifiers 147 and 181 act as low pass filters and thus essentially pass only DC signals, because the light reflected from the base material of the document 53 causes the light sensors 102 and 104 to develop signals which are essentially DC signals, and because the signals developed by those light sensors when the "see" colored areas or lines on that document are essentially AC signals, the sum amplifier 152 and the difference amplifier 195 will essentially respond only to signals corresponding to the average lightness of the base material of the document 53. The overall result is that the circuits of FIG. 8 effectively compensate for the changes in gain which inherently occur during the operation of the light sensors 102 and 104. If desired, gates which are similar to the gates 282 and 286 in FIG. 9 and which are controlled by a signal on conductor 465 in the manner described hereinafter, may be inserted between junction 130 and resistor 136 in FIG. 8, and also between junction 166 and resistor 170 in FIG. 8. Those gates would serve to disconnect the gain control circuits from the light sensors 102 and 104 when those light sensors were "seeing" colored areas on the document 53. The addition of such gates would not be necessary for a color identification unit which was intended to read documents that had only a small percentage of the total area printed in colors, as is the case with most maps.

C. Operation of Color Contrast And Latitude Computer Block

As explained in the Brief Description of Operation of Color Identification Unit, the squaring circuit 368, the delay circuit 380, the sum amplifier 387, and the rejection filter 394 convert the $L_1 + 1.41 S_1 \sin \omega t$ signal from the light sensor 104 to $2(L_1)^2 + 2(S_1)^2$ or $2(C_1)^2$. Similarly, the squaring circuit 370, the delay circuit 404, the sum amplifier 413, and the rejection filter 418 convert the $L + 1.41 S \sin \omega t$ signal from the light sensor 102 to $2L^2 + 2S^2$ or $2C^2$. Also, the squaring circuit 368 and the low frequency band-pass filter 430 and the squaring circuit 370 and the low frequency band-pass filter 432 coact with OR gate 434 to convert the $L_1 + 1.41 S_1 \sin \omega t$ signal from the light sensor 104 to $(L_1)^2$ or to convert the $L + 1.41 S \sin \omega t$ signal from the light sensor 102 to L^2 . The OR gate 436 will apply the $2(C_1)^2$ signal or the $2C^2$ signal to the lower input of the multiplier 440, and the OR gate 434 will apply the $(L_1)^2$ or the L^2 signal to the upper input of the multiplier 438.

The multiplier 438 develops an output signal which is directly equal to the product of the two signals applied to the inputs thereof; and, similarly, the multiplier 440 develops an output signal which is directly equal to the product of the two signals applied to the inputs thereof. The amplifier 450 is an operational amplifier with a frequency response that is high enough to avoid appreciable attenuation of signals in the range of 20 kilocycles per second.

The multiplier 440 has the left-hand input thereof connected directly to the output of the amplifier 450, and has the output thereof connected to the input of that amplifier by resistor 454 and junction 455; and hence that multiplier is connected in the feedback loop of that amplifier. As a result, that multiplier will coact with that amplifier to provide a dividing action. Specifically, the multiplier 440 will coact with the amplifier 450 to divide the value of the voltage which the reference connected to the terminal 444 establishes at the junction 455 by the $2C^2$ signal or the $2(C_1)^2$ signal which the OR gate 436 applies to the lower input of that multiplier. By making the value of the voltage which the reference connected to the terminal 444 establishes at the junction 455 equal to 2, the color identification unit effectively divides 2 by $2(C_1)^2$ or by $2C^2$ to produce a $\frac{1}{(C_1)^2}$ signal or a $\frac{1}{C^2}$ signal at the junction 452, and thus at the lower input of the multiplier 438. That multiplier then multiplies the $(L_1)^2$ by the $\frac{1}{(C_1)^2}$ signal or multiplies the L^2 signal by the $\frac{1}{C^2}$ signal to produce a $\frac{(L_1)^2}{(C_1)^2}$ signal or a $\frac{L^2}{C^2}$ signal which represents the square of the cosine of the latitude angle of the pigment "seen" by the light sensors 102 and 104.

When both of the light sensors 102 and 104 "see" the base material of the document 53, L and L_1 will equal zero and S and S_1 also will equal zero. When those values are incorporated into the equation $2L^2 + 2S^2 = 2C^2$, $2C^2$ will equal zero. When a zero voltage is applied to the lower input of multiplier 440, its output will be zero for any value applied to its other input. The amplifier 450 will thus reach a maximum output, due to the input at 444 and no feedback through multiplier 440, and the multiplier 440 will have a maximum gain for any input signal which may appear at its lower input. As the value of $2(C_1)^2$ or $2C^2$ signal increases—which occurs when a printed area moves into view of the sensors 102 and 104—the output of multiplier 440 will increase in proportion until it is equal to the signal at the input 444. The $2(C_1)^2$ or $2C^2$ signal at this time is at a threshold level, since further increase will cause the amplifier 450 output to decrease and to correspondingly decrease the gain of the multipliers 440 and 438. The quotient L^2 divided by C^2 is not valid until the value of C^2 has exceeded that threshold.

If both of the light sensors 102 and 104 were to "see" a pigment which reflected all red and green light falling upon it and absorbed all blue light falling upon it. L and L_1 would both equal L and S and S_1 would both equal 1.41, as indicated by FIG. 24; wherein the line 1090 indicates the lightness of that pigment, and the lines 1,092 and 1,094 subtend the saturation value of that pigment. When those values are incorporated into the equation $2L^2 + 2S^2 = 2C^2$, C^2 will equal 3; and the quotient of L^2 divided by C^2 will be 0.333. This means that the square of the cosine of the latitude angle of such a pigment would be 0.333.

In actual practice, no pigment will reflect all red and green light falling upon it and absorb all blue light falling upon it; and hence the square of the cosine of the latitude angle of a typical yellow pigment will be different from 0.333—being for example 0.28. Although based upon a theoretical pigment, the illustration given by FIG. 24 is useful in showing how a pigment which can absorb only one of the three basic colors of light used to form the spot 90 of light can have a positive-going zero crossing which is 300° —and thus has a longitude angle of minus 60° , as shown by FIG. 25. Further, that illustration shows how that pigment can have a latitude angle with a cosine squared of 0.333—and thus a latitude angle of about 55° . The longitude angle of -60° , will coact with the 0.333 value for the square of the cosine of the latitude angle of that pigment to positively identify that pigment as a yellow pigment.

When both of the light sensors 102 and 104 "see" an orange pigment, L and L_1 will both equal 1.44 and S and S_1 will both

equal 0.855, as indicated by FIG. 26; wherein the line 1096 indicates the lightness of that pigment, and the lines 1,098 and 1100 subtend the saturation value of that pigment. When those values are incorporated into the equation $2L^2 + 2S^2 = 2C^2$ C^2 will equal 2.80; and the quotient of L^2 divided by C^2 will be 0.74. This means that the square of the cosine of the latitude angle of the orange pigment will be 0.74.

In FIGS. 23 and 24, the amplitudes of the waveforms 1042 and 992 corresponding to the red components in the reflected light are the same, because the theoretical pigment represented by FIG. 24 reflects all of the red light falling upon it; and, similarly, the amplitudes of the waveforms 1,046 and 990 corresponding to the green components in the reflected light are the same, because the theoretical pigment represented by FIG. 24 reflects all of the green light falling upon it. However, as indicated by FIG. 26, the amplitude of the waveform 1,102 corresponding to the red component of the reflected lights is about 90 percent of the amplitude of the waveform 1042 in FIG. 23, the amplitude of the waveform 1,104 corresponding to the blue component of the reflected light is about 21 percent of the amplitude of the waveform 1,044, and the amplitude of the waveform 1106 corresponding to the green component of the reflected light is about 45 percent of the amplitude of the waveform 1046. Those red, blue and green components of reflected light coact to develop an AC signal 1118 which has a positive-going zero crossing of 340° . That positive-going zero crossing and the 0.74 square of the cosine of the latitude angle positively identify the pigment as being an orange pigment.

When both of the light sensors 102 and 104 "see" areas which are half-white and half-orange, as when the interface between the base material and an orange area on the document 53 is being "seen" by those light sensors, L and L_1 will both equal 0.72 and S and S_1 will both equal 0.427, as indicated by FIG. 27; wherein the line 1,120 indicates the lightness of the area "seen" by those light sensors, and the lines 1,122 and 1,124 subtend the saturation value of that area. When those values are incorporated into the equation $2L^2 + 2S^2 = 2C^2$, $2C^2$ will equal 1.42; and the quotient of L^2 divided by C^2 will be 0.74. This means that the square of the cosine of the latitude angle of an area which is half-white and half-orange is the same as the square of the latitude angle of an area which is all orange.

The amplitude of the waveform 1126 in FIG. 27 which corresponds to the red component of the reflected light is about 95 percent of the amplitude of the waveform 1042 in FIG. 23, the amplitude of the waveform 1128 corresponding to the blue component of the reflected light is about 62½ percent of the amplitude of the waveform 1,044 and the amplitude of the waveform 1,130 corresponding to the green component of the reflected light is about 72½ percent of the amplitude of the waveform 1046.

The amplitudes of the waveforms 1126, 1128 and 1180 of FIG. 27 are, respectively, larger than the amplitudes of the waveforms 1102, 1104 and 1106 of FIG. 26—because of the white in the light reflected from the base material—but, importantly, those waveforms coact to develop an AC signal 1132 which has a positive-going zero crossing which is the same as the positive-going zero crossing of the AC signal 1,118 of FIG. 26. This means that although the lightness values of the signals developed by the light sensors 102 and 104 will vary as those light sensors "see" only a colored area and then "see" the interface between that colored area and the base material of the document 53, the color identification unit will develop the same positive-going zero crossing and will develop the same square of the cosine of the latitude angle of the pigment used in drawing or printing that colored area; and hence that color identification unit will positively identify that pigment. The fact that the color identification unit will be able to develop the same positive-going zero crossing and will be able to develop the same square of the cosine of the latitude angle of the pigment despite variations in the lightness of the area "seen" by the light sensors 102 and 104 enables that color identification unit to positively identify a pigment that is used to print or draw a document 53—whether that pig-

ment substantially or insubstantially fills the interstices and fibers of the base material of that document.

In the immediately-preceding illustrations, it was assumed that the light sensors 102 and 104 "saw" the same colored area; and, where that was the case, the lightness values and the saturation values of the electric signal developed by those light sensors were equal. Where the light sensor 102 "sees" a colored area while the light sensor 104 "sees" the base material of the document 53, the lightness value and the saturation value of the electric signal developed by the light sensor 104 will be essentially zero; and hence the circuit of FIG. 10 will respond to the lightness value and the saturation value of the electric signal developed by the light sensor 102. Where the light sensor 102 "sees" a colored area while the light sensor 104 "sees" a black line on the document 53, the lightness value of the electric signal developed by the light sensor 104 will be at a maximum and the saturation value of that electric signal will be at a minimum; and hence the circuit of FIG. 10 will respond to the lightness value and the saturation value of the electric signal developed by the light sensor 104. Where the light sensor 102 "sees" a colored area while the light sensor 104 "sees" a different colored area—as when the boundary between two colored areas on the document 53 is being scanned—the OR gate 434 will respond to the larger of the L^2 or $(L_1)^2$ signals, and the OR gate 436 will respond to the larger of the $2C^2$ or $2(C_1)^2$ signals.

D. Operation of Hue Reference Generator Block

The card reader 232 in FIG. 11 will respond to cards inserted therein to develop a number of fixed 7 bit words, and to apply those words to the words comparators of the Hue Position Control blocks 238 and 240. To enable those Hue Position Control blocks to provide the "angle slots" shown by FIGS. 29 and 31, that card reader will supply the 7 bit word 0001010 to the word comparator 243 of FIG. 16 via cable 211, will supply the 7 bit word 0001011 to the word comparator 588 of FIG. 17 via cable 185, will supply the 7 bit word 0010001 to the word comparator 589 of FIG. 17 via cable 187, will supply the 7 bit word 0010111 to the word comparator 590 of FIG. 17 via cable 189, will supply the 8 bit word 0100101 to the word comparator 591 of FIG. 17 via cable 191, will supply the 7 bit word 0101110 to the word comparator 592 of FIG. 17 via cable 193, will supply the 7 bit word 0110010 to the word comparator 245 of FIG. 16 via cable 213, will supply the 7 bit word 0111100 to the word comparator 247 of FIG. 16 via cable 215 and also will supply that 7 bit word to the word comparator 593 of FIG. 17 via cable 197, will supply the 7 bit word 1000110 to the word comparator 248 of FIG. 16 via cable 127, will supply the 7 bit word 1001011 to the word comparator 594 of FIG. 17 via cable 199, will supply the 7 bit word 1011011 to the word comparator 595 of FIG. 17 via cable 201, will supply the 7 bit word 1100101 to the word comparator 241 of FIG. 16 via cable 209, will supply the 7 bit word 1101010 to the word comparator 596 of FIG. 17 via cable 203, and will supply the 7 bit word 1110111 to the word comparator 587 of FIG. 17 via cable 183. The counter 246 will, during each cycle thereof, supply 7 bit words to each of the word comparators of the Hue Position Control blocks 238 and 240; and those 7 bit words will progressively and rapidly change from binary number 0 through binary number 119. As that counter supplies the binary number 10 to the word comparator 243 of FIG. 16, each bit comparator of that word comparator will have a "match;" and hence that word comparator will have a "match" and will apply a signal to the second uppermost conductor of cable 303. In rapid succession, the binary number 11 will provide a "match" in word comparator 588 of FIG. 17 to apply a signal to the second uppermost conductor of cable 301, the binary number 17 will provide a "match" in word comparator 589 to apply a signal to the third uppermost conductor of cable 301, the binary number 17 will provide a "match" in word comparator 589 to apply a signal to the fourth uppermost conductor of cable 301, the binary number 37 will provide a "match" in word comparator 591 to apply a signal to the fifth uppermost conductor of cable 301, the binary number 46 will provide a "match" in word comparator 592 to apply a signal to

the sixth uppermost conductor of cable 301, the binary number 50 will provide a "match" in word comparator 245 of FIG. 16 to apply a signal to the third uppermost conductor of cable 303, the binary number 60 will provide "match" in word comparator 247 of FIG. 16 and also in the word comparator 593 of FIG. 17 to apply signals, respectively, to the fourth uppermost conductor of cable 303 and to the seventh uppermost conductor of cable 301, the binary number 70 will provide a "match" in word comparator 248 of FIG. 16 to apply a signal to the lowermost conductor of cable 303, the binary number 75 will provide a "match" in word comparator 594 to apply a signal to the eighth uppermost conductor of cable 301, the binary number 91 will provide a "match" in word comparator 595 to apply a signal to the ninth uppermost conductor of cable 301, the binary number 101 will provide a "match" in word comparator 241 to apply a signal to the uppermost conductor of cable 303, the binary number 106 will provide a "match" in word comparator 596 to apply a signal to the lowermost conductor of cable 301, and the binary number 119 will provide a "match" in word comparator 587 to apply a signal to the uppermost conductor of cable 301. The counter 246 will recycle every 5 microseconds and hence each of the word comparators of the Hue Position Control blocks 238 and 240 will have a "match" every 5 microseconds.

The card reader 232 and the counter 246 supply the 7-bit words which the Phase Control Circuit block 234 utilizes to develop the waveforms shown in FIG. 22. In addition that card reader supplies the digital words which the Latitude Control Subcircuits block 332 of FIG. 13 utilizes to provide analogue signals for the comparators 333, 334, 335, 336 and 338 of FIG. 13.

E. Operation of Line Sensing Block

The $2C^2$ signal, which the rejection filter 418 of FIG. 10 supplies to the junction 468 in FIG. 15, will be applied directly to the input of amplifier 482 and to the lower input of OR gate 514, but will be delayed by the delay circuit 472 before it is applied to the input of amplifier 502 and to the lower input of OR gate 518. The $2(C_1)^2$ signal, which the rejection filter 394 of FIG. 10 supplies to the junction 466 in FIG. 15, will be applied directly to the input of amplifier 502 and to the upper input of OR gate 518, but will be delayed by the delay circuit 470 before it is applied to the input of amplifier 482 and to the upper input of OR gate 514. The amplifier 482 and the OR gate 514 thus will receive signals corresponding to the areas 960 and 964 shown in FIG. 33, and the amplifier 502 and the OR gate 518 will receive signals corresponding to the areas 962 and 963.

The OR gate 514 will respond to the larger of the signals corresponding to the areas 960 and 964 to develop an output signal; and the sum amplifier 487 will add the signals corresponding to the areas 960 and 964 but will invert the sign of the resulting sum. Similarly, the OR gate 518 will respond to the larger of the signals corresponding to the areas 962 and 963 to develop an output signal; and the sum amplifier 507 will add the signals corresponding to the areas 962 and 963 but will invert the sign of the resulting sum. In summing the signals corresponding to the areas 960 and 964 the sum amplifier 487 develops a signal which corresponds to a signal that would be developed by the light sensors 102 and 104 if they "saw" an elongated area that was inclined to the direction of scanning of the document 53. In summing the signals corresponding to the areas 962 and 963 the sum amplifier 507 develops a signal which corresponds to a signal that would be developed by the light sensors 102 and 104 if they "saw" an elongated area that was inclined to the direction of scanning of the document 53 and was displaced 90° from the first elongated area.

The OR gate 514 will respond to the signal corresponding to the area 960 or to the signal corresponding to the area 964, whichever is the greater; and, similarly, the OR gate 518 will respond to the signal corresponding to the area 962 or to the signal corresponding to the area 963, whichever is the greater. The resistor 516 has an ohmic value equal to just one-half of

the ohmic value of the resistor 490; and, similarly, the resistor 520 has an ohmic value equal to just one-half of the ohmic value of the resistor 510. The resistor 534 of sum amplifier 537 has an ohmic value equal to the ohmic value of resistor 490, and thus equal to twice the ohmic value of resistor 516; and, similarly, the resistor 542 of sum amplifier 545 has an ohmic value equal to the ohmic value of resistor 510, and thus equal to twice the ohmic value of resistor 520.

The sum amplifier 537 will, because the ohmic value of resistor 516 is one-half of the ohmic value of resistor 490, effectively double the value of the output signal from OR gate 514 relative to the value of the output signal from sum amplifier 487. Similarly, the sum amplifier 545 will, because the ohmic value of resistor 520 is one-half of the ohmic value of resistor 510, effectively double the value of the output from OR gate 518 relative to the value of the output signal from sum amplifier 507. Also, the sum amplifiers 537 and 545 will invert the signs of the signals supplied to the inputs thereof. If the signal corresponding to the area 960 is represented by the letter A , if the signal corresponding to the area 963 is represented by the letters AA , if the signal corresponding to the area 962 is represented by the letter B , and if the signal corresponding to the area 964 is represented by the letters BB , the output of the sum amplifier 537 will be $A+BB-2A$ as long as A is greater than BB and will be $A+BB-2BB$ when BB is greater than A ; and the output of the sum amplifier 545 will be $AA+B-2AA$ as long as AA is greater than B and will be $AA+B-2B$ when B is greater than AA . This means that the output of the sum amplifier 537 will be the absolute value of $A-BB$, and that the output of the sum amplifier 545 will be the absolute value of $AA-B$. As a result, the sum amplifier 537 will provide no signal at the output thereof when the instantaneous value of A is equal to the instantaneous value of BB , as when the light sensors 102 and 104 are both "seeing" the base material or the same colored area or part of the same line on the document 53; but that sum amplifier will provide an output whenever either of those light sensors "sees" the base material, a colored area, or a part of a line on the document 53 and the other of those light sensors does not. Similarly, the sum amplifier 545 will provide no signal at the output thereof when the instantaneous value of AA is equal to the instantaneous value of B , as when one of the light sensors 102 and 104 "sees" the base material, a colored area, or part of a line on the document 53 and the other of those light sensors does not. As a result, the Line Sensing block 460 in FIG. 4 will leave the gate generator 548 thereof "off" whenever the light sensors 102 and 104 are both "seeing" equivalent portions of a document 53—whether those equivalent portions are parts of the base material, parts of a given colored area, or part of the same line; but that Line Sensing block will turn that gate generator "on" whenever one of those light sensors "sees" the base material, a colored area, or part of a line on the document 53 and the other of those light sensors does not. In its "off" state, the gate generator 548 applies a signal to the lower input of AND gate 529; but in its "on" state that gate generator does not apply a signal to that lower input. In its "off" state, the gate generator 524 develops a signal at the upper output thereof and does not develop a signal at the lower output thereof.

Whenever both of the light sensors 102 and 104 "see" the base material of the document 53, the $2C^2$ and $2(C_1)^2$ signals applied to the junctions 466 and 468 in FIG. 15 will effectively be zero; and the values of A , B , AA and BB will all be zero. At such time, the input to the gate generator 524, as well as the input to the gate generator 548 will be zero; and while the latter gate generator will apply a signal to the lower input of the AND gate 529, the former gate generator will not apply a signal to the upper input of that AND gate. This means that whenever both of the light sensors 102 and 104 "see" the base material of the document 53, the Line Sensing block 460 of FIG. 4 will not supply a signal to the Digital Code Generator block 556—and, because the latter block does not receive such a signal, it will keep the Buffer And Data Record Control block 580 from supplying a signal to the Recorder block 582.

The $2C^2$ signal, which is developed by the circuit of FIG. 10 as the light sensor 102 "sees" the area 960 in FIG. 33, will experience a change in amplitude as the line 965 moves relative to the center of the array of areas; as indicated by the waveform 966 in FIG. 34. Similarly, the $2(C_1)^2$ signal, which is developed by the circuit of FIG. 10 as the light sensor 104 "sees" the area 962, will experience a change in amplitude as the line 965 moves relative to that array of areas; also as indicated by the waveform 966 in FIG. 34. The waveform 966 can represent the changes in amplitude of both the $2C^2$ and $2(C_1)^2$ signals because the areas 960 and 962 are identical in size and because a line connecting the geometric centers of those areas is precisely parallel to the line 965. The dashed-line waveform 967 in FIG. 34 represents the waveform corresponding to the $2C^2$ and $2(C_1)^2$ signals after those signals have been delayed, respectively, by the delay circuits 472 and 470.

When the center of the array of areas is at point 1 relative to the line 965 in FIG. 33, no part of that line is in either of the areas 960 and 962; and hence the waveform 966 has zero amplitude. However, when the center of the array of areas is at point 2, the left-hand edge of line 965 has just entered the right-hand portions of the areas 960 and 962; and hence the waveform 966 has begun to rise. When the center of the array of areas is at point 3, the left-hand edge of line 965 has passed to the left of the centers of the areas 960 and 962; and hence the maximum amplitude of waveform 966 has been reached and passed. When the center of the array of areas is at point 4, the left-hand edge of the line 965 has passed beyond the left-hand edges of the areas 960 and 962—with a further decrease in the amplitude of waveform 966; and when the center of the array of areas is at point 5, the right-hand edge of line 965 is just about to leave the areas 960 and 962. When the center of the array of areas is at point 6, the line 965 has moved wholly to the left of the areas 960 and 962; and the amplitude of waveform 966 again is zero.

The sum amplifier 487 will receive the waveform 966 in FIG. 34, developed as the line 965 passed through the area 960, and also will receive the waveform 967, obtained by delaying the signal developed when the line 965 passed through the area 962; and that sum amplifier will sum those waveforms and invert them to produce the waveform 968 in FIG. 35. The OR gate 514 will respond to whichever of the signals applied to the inputs thereof is greater at any given instant; and hence it will respond to the first part of the waveform 966 in FIG. 34 to develop the first half of the waveform 970 in FIG. 36, and then it will respond to the latter portion of the waveform 967 in FIG. 34 to produce the last half of the waveform 970. Similarly, the sum amplifier 507 will receive the waveform 966 in FIG. 34, developed as the line 965 passed through the area 962, and also will receive the waveform 967, obtained by delaying the signal developed when the line 965 passed through the area 960; and that sum amplifier will sum and invert them to produce from those waveforms a waveform identical to the waveform 968 in FIG. 35. The OR gate 518 will respond to whichever of the signals applied to the inputs thereof is the greater at any given instant; and hence it will respond to the first part of the waveform 966 in FIG. 34 to develop the first half of the waveform 970 in FIG. 36, and then it will respond to the latter portion of the waveform 967 in FIG. 34 to develop the last half of the waveform 970.

The signals at the outputs of the sum amplifiers 487 and 507 will be applied to the input of the OR gate 522; and that OR gate will provide a waveform which is substantially identical to the waveform 968 in FIG. 35. The signal at the output of the sum amplifier 487 will be applied to the input of the amplifier 532 of the sum amplifier 537 by the resistor 490; and the signal at the output of the OR gate 514 will be applied to the input of the amplifier 532 by the resistor 516. The latter resistor has just one-half the ohmic value of the former resistor; and hence the sum amplifier 537 will sum the signals at the outputs of the sum amplifier 487 and of the OR gate 514—inverting both of those signals as it does so, and also effectively

doubling the relative value of the signal at the output of the OR gate 514. The signal at the output of the sum amplifier 537 will be $A+BB-2A$ as long as A is greater than BB —as shown by the first half of the waveform 971 in FIG. 37—and will be $A+B-BB$ when BB is greater than A —as shown by the last half of the waveform 971. The instantaneous value of A will equal the instantaneous value of BB at the center of the waveform 971 in FIG. 37—causing that waveform to go to zero. The signal at the output of the sum amplifier 507 will be applied to the input of the amplifier 540 of the sum amplifier 545 by the resistor 510; and the signal at the output of the OR gate 518 will be applied to the input of the amplifier 540 by the resistor 520. The latter resistor has just one-half the ohmic value of the former resistor; and hence the sum amplifier 545 will sum the signals at the outputs of the sum amplifier 507 and of the OR gate 518—inverting both of those signals as it does so, and also effectively doubling the relative value of the signal at the output of the OR gate 518. The signal at the output of the sum amplifier 545 will be $B+AA-2B$ as long as B is greater than AA —as shown by the first half of the waveform 971 in FIG. 37—and will be $B+AA-2AA$ when AA is greater than B —as shown by the last half of the waveform 971. The instantaneous value of B will equal AA at the center of the waveform 971 in FIG. 37—causing that waveform to go to zero. The signals at the outputs of the sum amplifiers 537 and 545 will be applied to the inputs of OR gate 546; and, because those signals are identical and are represented by the waveform 971 in FIG. 37, the output of that OR gate also will be represented by the waveform 971.

As shown by FIG. 35, the gate generator 524 has a threshold level denoted by the line 969; and, as shown by FIG. 37, the gate generator 548 has a threshold level denoted by the line 981. The waveforms 973 and 975 in FIG. 38 show the signals which appear at the upper and lower outputs, respectively, of the gate generator 524; and those waveforms show that whenever the input signal of the gate generator 524 is above the threshold level 969, a signal will appear at the upper output of that gate generator but no signal will appear at the lower output of that gate generator, and that whenever the signal at the input of that gate generator is below the threshold level 969 a signal will appear at the lower output of that gate generator but no signal will appear at the upper output of that gate generator. Consequently, a signal will appear at the upper output of the gate generator 524 but no signal will appear at the lower output of that gate generator until the waveform 968 in FIG. 35 falls below the threshold level 969; and, thereafter, as long as that waveform remains below that threshold level, the signal at the upper output of that gate generator will be zero, and a signal will appear at the lower output of that gate generator. Subsequently, as the waveform 968 moves back up above the threshold level 969, the signal at the upper output of the gate generator 524 will reappear and the signal at the lower output of that gate generator will disappear.

As shown by FIGS. 35 and 37, the threshold level of the gate generator 524 is greater than the threshold level of the gate generator 548. The waveform 977 in FIG. 38 shows the signal which appears at the upper output of AND gate generator 548; and that waveform shows that a signal appears at the upper output of that gate generator as long as the signal at the input of that gate generator is above the threshold level 981 but disappears whenever the signal at that input is below that threshold level. This means that a signal appears at the upper output of the gate generator 548 as long as the waveform 971 in FIG. 37 is above the threshold level 981, that signal disappears when that waveform falls below that threshold level, that signal reappears when that waveform rises above the threshold level 981 as indicated by the numeral 972, that signal disappears again when that waveform again falls below that threshold level, and that signal reappears again when that waveform again rises above that threshold level.

The AND gate 529 can develop a signal at the output thereof; and the waveform 979 in FIG. 38 shows that signal. That AND gate can develop that signal and can apply that

signal to the Computer Buffer block 570 of FIG. 14 only when signals are applied to both of the inputs thereof. As indicated by the waveform 975 of FIG. 38 a signal is applied to the upper input of that AND gate throughout the entire period when the waveform 968 in FIG. 35 is below the threshold level 969; but, as indicated by the waveform 979, a signal is applied to the lower input of that AND gate only when the waveform 971 is above the threshold level 981. The only period during which signals appear at both of the inputs of the AND gate 529 is indicated by the square pulse at the center of the waveform 979 in FIG. 38; and the application of that pulse to the Computer Buffer block 570 in FIG. 14 by the AND gate 529 indicates that the center of the array of areas shown in FIG. 33 is at the center of the line 965.

In FIG. 33, the line 695 on the document 53 was parallel to a line connecting the centers of the areas 960 and 962; and hence the waveforms developed by the light sensors 102 and 104 were congruent. In FIG. 39, however, a line 993 is inclined to a line connecting the centers of the areas 960 and 962, and hence the waveforms developed by the light sensors 102 and 104 will be different. When the center of the array of areas in FIG. 39 is at point 1 relative to the line 993, the left-hand edge of that line will just have entered the area 960 and will be spaced wholly away from the area 962; and hence the waveform 994 in FIG. 40 which corresponds to the signal developed when the light sensor 102 "sees" the area 960 will have begun to rise, but the amplitude of the waveform 995 which corresponds to the signal developed when the light sensor 104 "sees" the area 962 will be zero. When the center of the array of areas is at point 2, the line 993 will be filling more than one-half of the area 960 and the amplitude of the waveform 994 will be more than one-half of its maximum value; but that line will not yet have entered the area 962 and the amplitude of the waveform 995 will still be zero. When the center of the array of areas is at point 3, the line 993 will be filling the area 960 and the amplitude of the waveform 994 will be at its maximum value; and the line 993 will be filling more than one-half of the area 962 and the amplitude of the waveform 995 will be greater than one-half of its maximum value. When the center of the array of areas is at point 4, the line 993 will be filling about one-half of the area 960 and the amplitude of the waveform 994 will be about one-half of its maximum value; and that line will be filling the area 962 and the amplitude of the waveform 995 will be at its maximum value. When the center of the array of areas is at point 5, the line 993 will be in just the left-hand portion of the area 960 and the amplitude of the waveform 994 will be close to zero; and that line will be filling about one-half of the area 962 and the amplitude of the waveform 995 will be about one-half of its maximum value. When the center of the array of areas is at point 6, the line 993 will be wholly to the left of the area 960 and the amplitude of the waveform 994 will be zero; and that line will be in just the left-hand portion of the area 962 and the amplitude of the waveform 995 will be close to zero. Before the center of the array of areas can reach point 7, the line 993 will be wholly to the left of the area 962 and the amplitude of the waveform 995 will be zero.

The line 993 will be parallel to a line connecting the centers of the areas 962 and 963; and hence the delayed signal corresponding to the area 960 will be congruent with the signal corresponding to the area 962. As a result, the waveform 995 will represent the delayed signal corresponding to the area 960 as well as the signal corresponding to the area 962. The waveform 996 will represent the delayed signal corresponding to the area 962.

The sum amplifier 487 will receive the waveform 994 in FIG. 40, developed as the line 993 passed through the area 960, and also will receive the waveform 996, obtained by delaying the signal developed when the line 993 passed through the area 962; and that sum amplifier will sum those waveforms and invert them to produce the waveform 999 in FIG. 41. The OR gate 514 will respond to the first part of the waveform 994 in FIG. 40 to develop the first half of the

waveform 1000 in FIG. 42; and it will respond to the second part of the waveform 996 to develop the second half of the waveform 1000. Similarly, the sum amplifier 507 will receive the waveform 995 in FIG. 40, developed as the line 993 passed through the area 962, and also will receive a duplicate of that waveform obtained by delaying the signal developed when the line 993 passed through the area 960; and that sum amplifier will sum those waveforms and invert them to produce the waveform 997 in FIG. 41. The OR gate 518 will respond to either of the waveforms 995 to develop the waveform 1001 in FIG. 42.

The signals at the outputs of the sum amplifiers 487 and 507 will be applied to the input of the OR gate 522; and that OR gate will respond to the signal at the output of the sum amplifier 487 whenever the signal $-(A+BB)$ is more positive than the signal $-(B+AA)$ at the output of the sum amplifier 507, and will respond to the signal at the output of the sum amplifier 507 whenever the signal $-(B+AA)$ is more positive than the signal $-(A+BB)$ at the output of the sum amplifier 487. The resulting waveform at the output of OR gate 522 is shown by solid lines in FIG. 41.

The signal at the output of the sum amplifier 487 also will be applied to the input of the amplifier 532 of the sum amplifier 537 by the resistor 490; and the signal at the output of the OR gate 514 also will be applied to the input of the amplifier 532 by the resistor 516. The sum amplifier 537 will sum the signals at the outputs of the sum amplifier 487 and of the OR gate 514—inverting both of those signals as it does so, and also effectively doubling the relative value of the signal at the output of the OR gate 514. The signal at the output of the sum amplifier 537 will be $A+BB-2A$ as long as A is greater than BB —as shown by the first half of the waveform 1002 in FIG. 43—and will be $A+B-2BB$ when BB is greater than A —as shown by the last half of the waveform 1002. The instantaneous value of A will equal the instantaneous value of BB at the center of the waveform 1002 in FIG. 43—causing that waveform to go to zero. The signal at the output of the sum amplifier 507 will be applied to the input of the amplifier 540 of the sum amplifier 545 by the resistor 510; and the signal at the output of the OR gate 518 will be applied to the input of the amplifier 540 by the resistor 520. The sum amplifier 545 will sum the signals at the outputs of the sum amplifier 507 and of the OR gate 518—inverting both of those signals as it does so, and also effectively doubling the relative value of the signal at the output of the OR gate 518. The signal at the output of the sum amplifier 545 will be $B+AA-2B$ or $B+AA-2A$; but since B and AA are congruent, the signal at the output of the sum amplifier 545 will be zero, as indicated by the line 1009 in FIG. 43. The signals at the outputs of the sum amplifiers 537 and 545 will be applied to the inputs of the OR gate 546; and, since the signal at the output of the sum amplifier 545 will be zero, that OR gate will respond to the signal at the output of the sum amplifier 537. As a result, the waveform 1002 in FIG. 43 will represent the signal at the output of the OR gate 546 as well as the signal at the output of the sum amplifier 537.

The waveforms 1004 and 1005 in FIG. 44 show the signals which appear at the upper and lower outputs, respectively, of the gate generator 524; and those waveforms show that whenever the input signal of the gate generator 524 is above the threshold level indicated by the line 1011 in FIG. 41, a signal will appear at the upper output of that gate generator but no signal will appear at the lower output of that gate generator, and that whenever the signal at the input of that gate generator is below the threshold level 1011 a signal will appear at the lower output of that gate generator but no signal will appear at the upper output of that gate generator. Consequently, a signal will appear at the upper output of the gate generator 524 but no signal will appear at the lower output of that gate generator until the waveform shown by solid lines in FIG. 41 falls below the threshold level 1011; and, thereafter, as long as that waveform remains below that threshold level, the signal at the upper output of that gate generator will be zero, and a signal will appear at the lower output of that gate

generator. Subsequently, as the solid-line waveform in FIG. 41 moves back up above the threshold level 1011, the signal at the upper output of the gate generator 524 will reappear and the signal at the lower output of that gate generator will disappear.

As shown by FIGS. 41 and 43, the threshold level of the gate generator 524 is greater than the threshold level 1013 of the gate generator 548. The waveform 1006 in FIG. 44 shows the signal which appears at the upper output of the gate generator 548; and that waveform shows that a signal appears at the upper output of that gate generator as long as the signal at the input of that gate generator is above the threshold level 1013 in FIG. 43, but disappears whenever the signal at that input is below that threshold level. This means that a signal appears at the upper output of the gate generator 548 as long as the waveform 1002 in FIG. 43 is above the threshold level 1013, that signal disappears when that waveform falls below that threshold level, that signal reappears when that waveform rises above the threshold level 1013 as indicated by the numeral 1003, that signal disappears again when that waveform again falls below that threshold level, and that signal reappears again when that waveform again rises above that threshold level.

The AND gate 529 will develop a signal at the output thereof only when signals are applied to both of the inputs thereof. As indicated by the waveform 1005 in FIG. 44, a signal is applied to the upper input of that AND gate throughout the entire period when the solid-line waveform in FIG. 41 is below the threshold level 1011; but, as indicated by the waveform 1006 in FIG. 44, a signal is applied to the lower input of that AND gate only when the waveform 1002 in FIG. 43 is above the threshold level 1013. The only period during which signals appear at both of the inputs of the AND gate 529 is indicated by the square pulse at the center of the waveform 1007 in FIG. 44; and the application of that pulse to the Computer Buffer block 570 in FIG. 14 by the AND gate 529 indicates that the center of the array of areas shown in FIG. 39 is at the center of the line 993.

In FIG. 45, a line 1052 is inclined to a line connecting the centers of the areas 960 and 962; and hence the waveforms developed by the light sensors 102 and 104 will be different. When the center of the array of areas in FIG. 45 is at point 1 relative to the line 1052, that line fills more than one-half of the area 960 but is wholly spaced away from the area 962, and hence the amplitude of the waveform 1054 in FIG. 46 which corresponds to the signal developed when the light sensor 102 "sees" the area 960 will be greater than one-half of its maximum value, but the amplitude of the waveform 1058 which corresponds to the signal developed when the light sensor 104 "sees" the area 962 will be zero. When the center of the array of areas is at point 2, the line 1052 will almost fill the area 960 and will be filling the lower right-hand portion of the area 962; and hence the amplitude of the waveform 1054 will be close to its maximum value, and the waveform 1058 will have begun to rise. When the center of the array of areas is at point 3, the line 1052 will be filling the area 960 and will be filling about one-half of the area 962; and hence the amplitude of the waveform 1054 will be at its maximum value, and the amplitude of the waveform 1058 will be about one-half of its maximum value. When the center of the array of areas is at point 4, the line 1052 will be filling about one-half of the area 960 and will be filling almost all of the area 962; and hence the amplitude of the waveform 1054 will be about one-half of its maximum value and the amplitude of the waveform 1058 will be close to its maximum value. When the center of the array of areas is at point 5, the line 1052 will be filling just the upper left-hand portion of the area 960 but will still be filling almost all of the area 962; and hence the amplitude of the waveform 1054 will be close to zero, and the amplitude of the waveform 1058 will be close to its maximum value. When the center of the array of areas is at point 6, the line 1052 will be wholly to the left of the area 960 but will be filling about one-half of the area 962; and hence the amplitude of the waveform 1054 will

be zero, and the amplitude of the waveform 1058 will be about one-half of its maximum value. When the center of the array of areas is at point 7, the line 1052 will be even further to the left of the area 960 and will fill just the upper left-hand portion of the area 962; and hence the amplitude of the waveform 1054 will be zero, and the amplitude of the waveform 1058 will be close to zero. As the center of the array of areas moves to the right of position 7, the line 1052 will move wholly to the left of the area 962, and then the amplitudes of both of the waveforms 1054 and 1058 will be zero. The waveform 1056 in FIG. 46 will represent the delayed signal corresponding to the area 960; and the waveform 1060 will represent the delayed signal corresponding to the area 962.

The sum amplifier 487 will receive the waveform 1054 in FIG. 46, developed at the line 1052 passed through the area 960, and also will receive the waveform 1060, obtained by delaying the signal developed when the line 1052 passed through the area 962; and that sum amplifier will sum those waveforms and invert them to produce the waveform 1064 in FIG. 47. The OR gate 514 will respond to the first part of the waveform 1054 in FIG. 46 to develop the first half of the waveform 1066 in FIG. 48 and it will respond to the second part of the waveform 1060 to develop the second half of the waveform 1066. Similarly, the sum amplifier 507 will receive the waveform 1058 in FIG. 46 developed as the line 1052 passed through the area 962 and will receive the waveform 1056, obtained by delaying the signal developed when the line 1052 passed through the area 960; and that sum amplifier will sum those waveforms and invert them to produce the waveform 1062 in FIG. 47. The OR gate 518 will respond to the first part of the waveform 1056 to form the first part of the waveform 1068 in FIG. 48, and will respond to the last part of the waveform 1058 to form the last part of the waveform 1068.

The signals at the outputs of the sum amplifiers 487 and 507 will be applied to the input of the OR gate 522; and that OR gate will respond to the signal at the output of the sum amplifier 487 whenever the signal $-(A+BB)$ is more positive than the signal $-(B+AA)$ at the output of the sum amplifier 507, and will respond to the signal at the output of the sum amplifier 507 whenever the signal $-(B+AA)$ is more positive than the signal $-(A+BB)$ at the output of the sum amplifier 487. The resulting waveform at the output of OR gate 522 is shown by solid lines in FIG. 47.

The signal at the output of the sum amplifier 487 also will be applied to the input of the amplifier 532 of the sum amplifier 537 by the resistor 490; the signal at the output of the OR gate 514 will be applied to the input of the amplifier 532 by the resistor 516. The sum amplifier 537 will sum the signals at the outputs of the sum amplifier 487 and of the OR gate 514—inverting both of those signals as it does so, and also effectively doubling the relative value of the signal at the output of the OR gate 514. The signal at the output of the sum amplifier 537 will be $A+BB-2A$ as long as A is greater than BB —as shown by the first half of the waveform 1070 in FIG. 49—and will be $A+B-BB$ when BB is greater than A —as shown by the last half of the waveform 1070. The instantaneous value of A will equal the instantaneous value of BB at the center of the waveform 1070 in FIG. 49—causing that waveform to go to zero. The signal at the output of the sum amplifier 507 will be applied to the input of the amplifier 540 of the sum amplifier 545 by the resistor 510; and the signal at the output of the OR gate 518 will be applied to the input of the amplifier 540 by the resistor 520. The sum amplifier 545 will sum the signals at the outputs of the sum amplifier 507 and of the OR gate 518—inverting both of those signals as it does so, and also effectively doubling the relative value of the signal at the output of the OR gate 518. The signal at the output of the sum amplifier 545 will be $B+AA-2B$ as long as B is greater than AA —as shown by the first half of the waveform 1072 in FIG. 49—and will be $B+AA-2AA$ when AA is greater than B —as shown by the last half of the waveform 1072. The instantaneous value of B will equal the instantaneous value of AA at the center of the

waveform 1072 in FIG. 49—causing that waveform to go to zero as indicated by the numeral 1074. The signals at the outputs of the sum amplifier 537 and 545 will be applied to the inputs of the OR gate 546; and, since the signal at the output of the sum amplifier 545 is more positive than the signal at the output of the sum amplifier 537—as shown by the waveforms 1072 and 1070 in FIG. 49, that OR gate will respond to the signal at the output of the sum amplifier 545. As a result, the waveform 1072 in FIG. 49 will represent the signal at the output of the OR gate 546 as well as the signal at the output of the sum amplifier 545.

The waveforms 1076 and 1078 in FIG. 50 show the signals which appear at the upper and lower outputs, respectively, of the gate generator 524; and those waveforms show that whenever the input signal of the gate generator 524 is above the threshold level indicated by the line 1017 in FIG. 47, a signal will appear at the upper output of that gate generator, but no signal will appear at the lower output of that gate generator, and that whenever the signal at the input of that gate generator is below the threshold level 1017 a signal will appear at the lower output of that gate generator but no signal will appear at the upper output of that gate generator. Consequently, a signal will appear at the upper output of the gate generator 524, but no signal will appear at the lower output of that gate generator until the waveform shown by solid lines in FIG. 47 falls below the threshold level 1017; and, thereafter, as long as that waveform remains below that threshold level, the signal at the upper output of that gate generator will be zero, and a signal will appear at the lower output of that gate generator. Subsequently, as the waveform shown by solid lines in FIG. 47 moves back up above the threshold level 1017, the signal at the upper output of the gate generator 524 will reappear and the signal at the lower output of that gate generator will disappear.

As shown by FIGS. 47 and 49, the threshold level 1017 of the gate generator 524 is greater than the threshold level 1019 of the gate generator 548. The waveform 1080 in FIG. 50 shows the signal which appears at the upper output of the gate generator 548; and that waveform shows that a signal appears at the upper output of that gate generator as long as the signal at the input of that gate generator is above the threshold level 1019 in FIG. 49 but disappears whenever the signal at that input is below that threshold level. This means that a signal appears at the upper output of the gate generator 548 as long as the waveform 1072 in FIG. 49 is above the threshold level 1019, that signal disappears when that waveform falls below that threshold level, that signal reappears when that waveform rises above the threshold level 1019 as indicated by the numeral 1074, that signal disappears again when that waveform again falls below that threshold level, and that signal reappears again when that waveform again rises above that threshold level.

The AND gate 519 will develop a signal at the output thereof only when signals are applied to both of the inputs thereof. As indicated by the waveform 1078 in FIG. 50, a signal is applied to the upper input of that AND gate throughout the entire period when the solid-line waveform in FIG. 47 is below the threshold level 1017; but, as indicated by the waveform 1080 in FIG. 50, a signal is applied to the lower input of that AND gate only when the waveform 1072 in FIG. 49 is above the threshold level 1019. The only period during which signals appear at both of the inputs of the AND gate 529 is indicated by the square pulse at the center of the waveform 1082 in FIG. 50 and the application of that pulse to the Computer Buffer block 570 in FIG. 14 by the AND gate 529 indicates that the center of the array of areas shown in FIG. 45 is at the center of the line 1052.

In FIG. 51, a colored area 1134 has the left-hand edge thereof parallel to a line connecting the centers of the areas 960 and 962; and hence the waveforms developed by the light sensors 102 and 104 will be congruent. When the center of the array of areas in FIG. 51 is at point 1 relative to the area 1134, that colored area will be spaced wholly away from the areas

960 and 962; and hence the amplitude of the waveform 1136 in FIG. 52 which corresponds to the signals developed when the light sensors 102 and 104 "see" the areas 960 and 962 will be zero. When the center of the array of areas is at point 2, the colored area 1134 will fill more than one-half of each of the areas 960 and 962, and hence the amplitude of the waveform 1136 will be greater than one-half of its maximum value. When the center of the array of areas is at point 3, the colored area 1134 will completely fill each of the areas 960 and 962, and hence the amplitude of the waveform 1136 will be at its maximum value; and that amplitude will remain at that maximum level until the right-hand edge of the colored area 1134 starts to move beyond the right-hand edges of the areas 960 and 962. Thereafter, the amplitude of the waveform 1136 will start to fall toward zero—reaching zero as the right-hand edge of the colored area 1134 moves wholly beyond the left-hand edges of the areas 960 and 962 in FIG. 51. The waveform 1138 in FIG. 52 represents the delayed signals developed as the light sensors 102 and 104 "see" the areas 960 and 962, respectively.

The sum amplifier 487 will receive the waveform 1136 in FIG. 52, developed as the colored area 1134 passed through the area 960, and also will receive the waveform 1138, obtained by delaying the signal developed when that colored area passed through the area 962; and that sum amplifier will sum those waveforms and invert them to produce the waveform 1140 in FIG. 53. The OR gate 514 will respond to the first part of the waveform 1136 in FIG. 52 to develop the first half of the waveform denoted by numeral 1144 in FIG. 54; and it will respond to the second part of the waveform 1138 in FIG. 52 to develop the second half of the waveform 1144. Similarly, the sum amplifier 507 will receive the waveform 1136 in FIG. 52, developed as the colored area 1134 passed through the area 962, and also will receive the waveform 1138, obtained by delaying the signal developed when that colored area passed through the area 960; and that sum amplifier will sum those waveforms and invert them to produce the waveform 1140 in FIG. 53. The OR gate 518 will respond to the first part of the waveform 1136 in FIG. 52 to develop the first half of the waveform 1144 in FIG. 54; and it will respond to the second part of the waveform 1138 to develop the second half of the waveform 1144.

The signals at the outputs of the sum amplifiers 487 and 507 will be applied to the input of the OR gate 522; and that OR gate will respond to the signal at the output of the sum amplifier 487 whenever the signal $-(A + BB)$ is more positive than the signal $-(B + AA)$ at the output of the sum amplifier 507 and will respond to the signal at the output of the sum amplifier 507 whenever the signal $31 (B + AA)$ is more positive than the signal $-(A + BB)$ at the output of the sum amplifier 487. The resulting waveform at the output of OR gate 522 is the waveform 1140 in FIG. 53.

The signal at the output of the sum amplifier 487 also will be applied to the input of the amplifier 532 of the sum amplifier 537 by the resistor 490; and the signal at the output of the OR gate 514 also will be applied to the input of the amplifier 532 by the resistor 516. The sum amplifier 537 will sum the signals at the outputs of the sum amplifier 487 and of the OR gate 514—inverting both of those signals as it does so, and also effectively doubling the relative value of the signal at the output of the OR gate 514. The signal at the output of the sum amplifier 537 will be $A + BB - 2A$ as long as A is greater than BB —as shown by the first half of the waveform 1146 in FIG. 55—and will be $A + BB - 2BB$ when BB is greater than A —as shown by the last half of the waveform 1146. The instantaneous value of A will equal the instantaneous value of BB throughout the central portion of the waveform 1146—causing that waveform to go to zero. The signal at the output of the sum amplifier 507 will be applied to the input of the amplifier 540 of the sum amplifier 545 by the resistor 510; and the signal at the output of the OR gate 518 will be applied to the input of the amplifier 540 by the resistor 520. The sum amplifier 545 will sum the signals at the outputs of the sum amplifier

507 and of the OR gate 518—inverting both of those signals as it does so, and also effectively doubling the relative value of the signal at the output of the OR gate 518. The signal at the output of the sum amplifier 545 will be $B + AA - 2B$ as long as B is greater than AA —as shown by the first half of the waveform 1146 in FIG. 55—and will be $B + AA - 2AA$ when AA is greater than B —as shown by the last half of the waveform 1146. The instantaneous value of B will equal the instantaneous value of AA throughout the central portion of the waveform 1146—causing that waveform to go to zero. The signals at the outputs of the sum amplifiers 537 and 545 will be applied to the inputs of the OR gate 546; and, since the signal at the output of the sum amplifier 537 will be congruent with the signal at the output of the sum amplifier 545, the waveform 1146 in FIG. 55 will represent the signal at the output of the OR gate 546 as well as the signal at the output of sum amplifier 537 and the signal at the output of the sum amplifier 545.

The waveforms 1150 and 1152 in FIG. 56 show the signals which appear at the upper and lower outputs, respectively, of the gate generator 524; and those waveforms show that whenever the input signal of the gate generator 524 is above the threshold level indicated by the line 1142 in FIG. 53 a signal will appear at the upper output of that gate generator but no signal will appear at the lower output of that gate generator, and that whenever the signal at the input of that gate generator is below the threshold level 1142, a signal will appear at the lower output of that gate generator but no signal will appear at the upper output of that gate generator. Consequently, a signal will appear at the upper output of the gate generator 524 but no signal will appear at the lower output of that gate generator until the waveform 1140 falls below the threshold level 1142; and, thereafter, as long as that waveform remains below that threshold level, the signal at the upper output of that gate generator will be zero, and a signal will appear at the lower output of that gate generator. Subsequently, as the waveform 1140 moves back up above the threshold level 1142, the signal at the upper output of the gate generator 524 will reappear and the signal at the lower output of that gate generator will disappear.

As shown by FIGS. 53 and 55, the threshold level of the gate generator 524 is greater than the threshold level 1158 of the gate generator 548. The waveform 1154 in FIG. 56 shows the signal which appears at the upper output of the gate generator 548; and that waveform shows that a signal appears at the upper output of that gate generator as long as the signal at the input of that gate generator is above the threshold level 1158 in FIG. 55 but disappears whenever the signal at that input is below that threshold level. This means that a signal appears at the upper output of the gate generator 548 as long as the waveform 1146 is above the threshold level 1158, that signal disappears when that waveform falls below that threshold level, that signal reappears when that waveform rises above the threshold level 1158, that signal disappears again when that waveform again falls below that threshold level, and that signal reappears again when that waveform again rises above that threshold level.

The AND gate 529 will develop a signal at the output thereof only when signals are applied to both of the inputs thereof. As indicated by the waveform 1152 in FIG. 56, a signal is applied to the upper input of that AND gate throughout the entire period when the waveform 1140 in FIG. 53 is below the threshold level 1142; but, as indicated by the waveform 1154 in FIG. 56, a signal is applied to the lower input of that AND gate only when the waveform 1146 is above the threshold level 1158. The only period during which signals appear at both of the inputs of the AND gate 529 is indicated by the rectangular pulse at the center of the waveform 1156 in FIG. 56; and the application of that pulse to the Computer Buffer block 570 in FIG. 14 by the AND gate 529 indicates that the array of areas shown in FIG. 51 is within a colored area on the document 53.

The Line Sensing block 460 is intended to perform three functions: first, it must apply a signal to the gates 282 and 286 of FIG. 9 and to the integrators of the Integrators blocks 313 and 608 of FIGS. 19A and 19B, respectively, whenever both of the light sensors 102 and 104 "see" the base material of a document; second, it must eliminate that signal when either of the light sensors 102 and 104 "sees" a line or colored area on the document 53; and third, it must supply a pulse to the Computer Buffer block 570 of FIG. 14 whenever both of those light sensors "see" a line or colored area. In performing those functions, that Line Sensing block must be able to sense lines which may have lightness values close to the lightness value of the base material of the document 53. A yellow line on a document 53 can have a lightness value close to the lightness value of the base material of that document—even though that base material is white; and, to sense such a line, the Line Sensing block 460 must respond to values of color contrast as well as to values of lightness. That Line Sensing block is able to respond to values of color contrast as well as to values of lightness; because the circuit of FIG. 10 supplies signals to the junctions 466 and 468 in FIG. 15 which contain values of color contrast. Thus, as pointed out hereinbefore, the signal applied to the junction 466 is $2(C_1)^2$ and the signal applied to the junction 468 is $2C_2^2$; and both of those signals contain values of color contrast.

In sensing the center of a line on a document 53, the diameter of the aperture 98 in the aperture plate 96 of FIG. 3 should be smaller than the width of the narrowest line on that document.

Inasmuch as most lines on documents have widths of at least ten thousandths of an inch, a range of aperture diameters between five-thousandths and twenty-thousandths of an inch should be adequate. An aperture diameter of five to ten thousandths of an inch would be very useful for documents wherein none of the lines were narrower than fifteen thousandths of an inch, an aperture diameter of ten thousandths to fifteen thousandths of an inch would be very useful for documents wherein none of the lines were narrower than twenty-thousandths of an inch wide, and an aperture diameter fifteen thousandths to twenty thousandths of an inch would be very useful for documents wherein none of the lines was narrower than twenty-five thousandths of an inch.

If the document 53 is a map which has latitude and longitude lines thereon, the Line Sensing block 460 of FIG. 4 will sense those lines as well as the rest of the lines on that document. Importantly, that Line Sensing block will develop signals corresponding to the lines and colored areas on that document which can be referenced to the same coordinates to which the signals corresponding to those latitude and longitude lines are referenced; and hence, if any computer techniques are used to straighten the latitude or longitude lines on a stretched or distorted document, the lines and colored areas on that document can be correspondingly straightened by those computer techniques. Similarly, the latitude and longitude line data can be used as a guide by the digital computer if that computer is used to convert the map data to a different projection. When the latitude and longitude line data is manipulated by the computer to fit the desired projection, the same manipulation will correspondingly convert all other map data to that desired projection.

F. Operation of Hue Comparator and Latitude Comparator Blocks

When the light sensors 102 and 104 "sees" a red area on the document 53, the positive-going zero crossing of the AC signal developed by those light sensors will occur immediately before the end of a cycle of the counter 246 or shortly after the beginning of the succeeding cycle of that counter; and, in either event, the word comparator 587 of FIG. 17 would previously have "set" the flip-flop 632 in FIG. 19A to enable that flip-flop to apply a signal to the upper input of AND gate 651. As a result, the signal supplied to the lower input of that AND gate by the Hue Zero Crossing Detector 302 and the Monostable Multivibrator 306 and the conductor 311, as the

positive-going zero crossing occurs, will actuate that AND gate and enable it to apply a signal to integrator 670 and thus to Comparator Reference Selector block 315. Succeeding positive-going zero crossings that occur while the light sensors 102 and 104 "see" the red area will enable the integrator 670, the Comparator Reference Selector block, the Amplitude Comparator 698, the Validity Comparator block 322, and AND gate 752 to apply a signal to the lower input of AND gate 896 in FIG. 21. Because the word comparator 241 of FIG. 16 had previously "set" the flip-flop 772 in FIG. 19B, the signal from that flip-flop and the signal from the Hue Zero Crossing Detector 302 and the Monostable Multivibrator 306 and the conductor 311 and junction 312 and conductor 606 caused the AND gate 782 to apply a signal to the integrator 792. Succeeding positive-going zero crossings that occur while the light sensors 102 and 104 "see" the red area will enable the integrator 792, the Comparator Reference Selector block 612, the Amplitude Comparator 808, the Validity Comparator block 626, and AND gate 844 to apply a signal to the upper input of AND gate 890 in FIG. 21. However, because a red pigment has relatively high lightness and saturation values, the latitude angle 42 in the color solid 20 of FIG. 1 will be large, and the signal which corresponds to the square of the cosine of the latitude angle of that pigment and which the circuit of FIG. 10 supplies to comparators 333, 334, 335, 336 and 338 in FIG. 13 will be too small to enable the comparator 333 to apply a signal to the middle input of AND gate 890 in FIG. 21. As a result, the NOR gate 352 will not have a signal at the input thereof, and thus will develop a signal at the output thereof and apply that signal to the upper input of AND gate 896. The resulting application of signals to both inputs of AND gate 896 will enable that AND gate to supply a signal to the Color Number Decode Matrix block 564 and that Color Number Decode Matrix block will supply a binary number to the Computer Buffer block 570 which will positively identify the pigment "seen" by the light sensors 102 and 104 as a red pigment.

If a lilac pigment is "seen" by the light sensors 102 and 104, the word comparator 590, the flip-flop 638, the AND gate 656, the integrator 676, the amplitude comparator 704, the AND gate 758, and AND gate 899 in FIG. 21 will coact with the NOR gate 352 to supply a signal to the Color Number Decode Matrix block 564 and that Color Number Decode Matrix block will supply a binary number to the Computer Buffer block 570 which will positively identify the pigment "seen" by the light sensors 102 and 104 as a lilac pigment. If a blue pigment is "seen" by the light sensors 102 and 104, the word comparator 592, the flip-flop 642, the AND gate 660, the integrator 680, the amplitude comparator 708, the AND gate 762, and AND gate 901 in FIG. 21 will coact with the NOR gate 352 to supply a signal to the Color Number Decode Matrix block 564 and that Color Number Decode Matrix block will supply a binary number to the Computer Buffer block 570 which will positively identify the pigment "seen" by the light sensors 102 and 104 as a blue pigment. If a cyan pigment is "seen" by the light sensors 102 and 104, the word comparator 593, the flip-flop 644, the AND gate 662, the integrator 682, the amplitude comparator 710, the AND gate 764, and AND gate 902 in FIG. 21 will coact with the NOR gate 352 to supply a signal to the Color Number Decode Matrix block 564 and that Color Number Decode Matrix block will supply a binary number to the Computer Buffer block 570 which will positively identify the pigment "seen" by the light sensors 102 and 104 as a cyan pigment. If a green pigment is "seen" by the light sensors 102 and 104, the word comparator 594, the flip-flop 646, the AND gate 664, the integrator 684, the amplitude comparator 712, the AND gate 766, and AND gate 903 in FIG. 21 will coact with the NOR gate 352 to supply a signal to the Color Number Decode Matrix block 564 and that Color Number Decode Matrix block will supply a binary number to the Computer Buffer block 570 which will positively identify the pigment "seen" by the light sensors 102 and 104 as a green pigment. If a yellow

pigment is "seen" by the light sensors 102 and 104, the word comparator 595, the flip-flop 648, the AND gate 666, the integrator 686, the amplitude comparator 714, the AND gate 768 and AND gate 904 in FIG. 21 would coact with the NOR gate 352 to supply a signal to the Color Number Decode Matrix block 564 and that Color Number Decode Matrix block will supply a binary number to the Computer Buffer block 570 which will positively identify the pigment "seen" by the light sensors 102 and 104 as a yellow pigment. If an orange pigment is "seen" by the light sensors 102 and 104, the word comparator 596, the flip-flop 650, the AND gate 668, the integrator 688, the amplitude comparator 716, the AND gate 770, and AND gate 905 in FIG. 21 will coact with the NOR gate 352 to supply a signal to the Color Number Decode Matrix block 564 and that Color Number Decode Matrix block will supply a binary number to the Computer Buffer block 570 which will positively identify the pigment "seen" by the light sensors 102 and 104 as an orange pigment.

When the light sensors 102 and 104 "see" a brown area on the document 53, the positive-going zero crossing of the AC signal developed by those light sensors will occur before the end of a cycle of the counter 246 or shortly after the beginning of the succeeding cycle of that counter; and, in either event, the word comparator 241 of FIG. 16 would previously have "set" the flip-flop 772 in FIG. 19B to enable that flip-flop to apply a signal to the upper input of AND gate 782. As a result, the signal supplied to the lower input of that AND gate by the Hue Zero Crossing Detector 302 and the Monostable Multivibrator 306 and the conductor 311 and the conductor 606, as the positive-going zero crossing occurs, will actuate that AND gate and enable it to apply a signal to integrator 792 and thus to Comparator Reference Selector block 612. Succeeding positive-going zero crossings that occur while the light sensors 102 and 104 "see" the brown area will enable the integrator 792, the Comparator Reference Selector block 612, the amplitude comparator 808, the Validity Comparator block 626, and AND gate 844 to apply a signal to the upper input of AND gate 890 in FIG. 21.

The card reader 231 and the Latitude Control Subcircuits block 332 of FIG. 13 will apply a latitude level signal to the upper input of comparator 333; and the circuit of FIG. 10 will supply a signal to the lower input of that comparator which will correspond to the square of the cosine of the latitude angle of the brown pigment. The comparator 333 will respond to those two signals to apply a signal to the middle input of the AND gate 890; and the comparator 342 will—because the pigment "seen" by the light sensors 102 and 104 is not black—apply a signal to the lower input of the AND gate 890. That AND gate will respond to the signals at the three inputs thereof to apply a signal to the Color Number Decode Matrix block 564 and to the NOR gate 352 via branched conductor 918; and that NOR gate will thus be kept from supplying a signal to any of the AND gates of the AND Gates block 558, and the signal applied to the Color Number Decode Matrix block 564 will positively identify the pigment "seen" by the light sensors 102 and 104 as a brown pigment.

The circuit of FIG. 10 also will supply its signal to the lower inputs of the comparators 334, 335, 336 and 338; and, if the brown pigment is darker than the pigments corresponding to one or more of these comparators, the said one or more comparators will apply a signal to the middle input of the AND gate to which it is connected. However, the only AND gate of the Coincidence Circuits block 602 which is receiving a signal at the upper input thereof is the AND gate 890; and hence any other AND gate in that block will be unable to develop a signal at the output thereof.

At the time the positive-going zero crossing occurs, while the light sensors 102 and 104 "see" the brown area on the document 53, the word comparator 587 corresponding to a red pigment, or the word comparator 595 corresponding to a yellow pigment, or the word comparator 596 corresponding to an orange pigment will have "set" the flip-flop to which it is connected; and that flip-flop will respond to the signal from

the Hue Zero Crossing Detector 302 and the Monostable Multivibrator 306 and the conductor 311 to apply a signal to the upper input of the AND gate to which it is connected. That AND gate, the integrator connected to it, the amplitude comparator connected to that integrator, and the AND gate connected to that amplitude comparator would apply a signal to the lower input of the appropriate AND gate in the AND Gates block 558; but the NOR gate 352 would not apply a signal to the upper input of that AND gate. As a result, only the AND gate 890 could supply a signal to the Color Number Decode Matrix block 564; and that signal would positively identify the pigment "seen" by the light sensors 102 and 104 as brown pigment.

If a purple pigment is "seen" by the light sensors 102 and 104, the word comparator 243, the flip-flop 774, the AND gate 784, the integrator 794, the amplitude comparator 810, the AND gate 846, and AND gate 891 in FIG. 21 would coact with a signal from the card reader 232 in FIG. 11 and Latitude Control Subcircuits block 332 and comparator 334 in FIG. 13, and with a signal from the circuit of FIG. 10 to apply a signal to NOR gate 352 which would keep that NOR gate from applying a signal to the upper input of any of the AND gates of AND Gates block 558 and also to apply a signal to the Color Number Decode Matrix block 564 which would positively identify the pigment "seen" by the light sensors 102 and 104 as a purple pigment. If an olive pigment is "seen" by the light sensors 102 and 104, the word comparator 248 in FIG. 16, the flip-flop 780 in FIG. 19B, the AND gate 790, the integrator 800, the amplitude comparator 816, the AND gate 852, and AND gate 894 in FIG. 21 would coact with a signal from the card reader 232 in FIG. 11 and Latitude Control Subcircuits block 332 and comparator 334 in FIG. 13, and with a signal from the circuit of FIG. 10 to apply a signal to NOR gate 352 which would keep that NOR gate from applying a signal to the upper input of any of the AND gates of AND Gates block 558 and also to apply a signal to the Color Number Decode Matrix block 564 which would positively identify the pigment "seen" by the light sensors 102 and 104 as an olive pigment. As these illustrations show, the color identification unit automatically and accurately distinguishes between pigments that have the same longitude angle and which have distinctively different squares of the cosines of the latitude angles thereof.

When the light sensors 102 and 104 "see" a black line or black area on the document 53, the circuit of FIG. 10 will supply a signal to the upper input of comparator 342 in FIG. 13 which will be large enough to cause the signal at the upper output of that comparator to disappear and to cause a signal to appear at the lower output of that comparator. That signal from FIG. 10 will be large enough to cause all of the comparators 333, 334, 335, 336 and 338 to develop signals at the outputs thereof and to apply those signals to the middle inputs of the AND gates 890, 891, 892, 893 and 894, respectively; but the disappearance of the signal at the upper output of comparator 342 will keep all of those AND gates from developing a signal at the outputs thereof. The signal which appears at the lower output of the comparator 342 will keep the NOR gate 352 from applying a signal to the upper input of any of the AND gates of the AND Gates block 558; and hence the only signal that will be applied to the Color Number Decode Matrix block 564 will be the signal at the lower output of comparator 342, and that signal will positively indicate that the light sensors 102 and 104 saw a black marking. The circuit of FIG. 15 will supply a signal to the Computer Buffer block 570 which will indicate whether that black marking was a black line or a black area; and, consequently, the color and nature of the marking "seen" by the light sensors 102 and 104 will be fully established.

In the event the light sensors 102 and 104 "see" a colored line pass through the spot 90 of light, those light sensors will develop signals that will enable the circuit of FIG. 15 to supply a pulse to the Computer Buffer block 570 which will establish the fact that a line has been "seen" by those light sensors; and the circuits of FIGS. 12, 16, 17, 19A, 19B and 21 will supply a

signal to the Color Number Decode Matrix block 564 which will positively identify the pigment of that colored area.

Specifically, if the light sensors 102 and 104 "see" an orange line on a white base material pass through the spot 90 of light, those light sensors will develop the waveform 1157 shown by FIG. 28. Lines 1158 and 1160 in FIG. 28 indicated how the saturation vector S of the waveform 1157 increases to a maximum and then decreases to zero as the orange line passes through the spot 90 of light; and the line 1162 indicates how the lightness vector L increases to a maximum and then decreases to zero as that orange line passes through the spot 90 of light. The word comparator 596 of FIG. 17 will "set" the flip-flop 650 of FIG. 19A during every cycle of the counter 246; and a positive-going zero crossing will be detected by the Hue Zero Crossing Detector block 302 of FIG. 12 at about 340° of each of those cycles. That flip-flop will then act through AND gate 668, integrator 688, amplitude comparator 716 and AND gate 770 of FIG. 19A to apply a signal to the lower input of AND gate 905 of FIG. 21; and, because the signal which the circuit of FIG. 10 will supply to the comparators 333, 334, 335, 336, 338 and 342 will be too small to enable any of those comparators to supply a signal to the NOR gate 352, that NOR gate will supply a signal to the upper input of AND gate 905. As a result, the AND gate 905 will supply a signal to the Color Number Decode Matrix block 564 which will positively indicate that the marking "seen" by the light sensors 102 and 104 was orange. The circuit of FIG. 15 will supply a square pulse to the Computer Buffer block 570—all as described in Section E hereof—and that square pulse will positively indicate that the orange marking "seen" by the light sensors 102 and 104 was a line and not a colored area. As a result, the color identification unit of the present invention can positively identify the pigments used in printing or drawing lines, as well as areas, on a document 53.

In the operation of the Hue Comparator block 300 of FIG. 4, the integrators 670, 672, 674, 676, 678, 680, 682, 684, 686 and 688 of the Integrators block 313 of FIG. 19A and the integrators 792, 794, 796, 798 and 800 of the Integrators block 608 of FIG. 19B will have signals applied to the bases of the NPN transistors 866 thereof by the upper output of the gate generator 524 of FIG. 15 as long as the light sensors 102 and 104 both "see" the base material of a document 53; and those transistors will respond to those signals to become conductive, and thus clamp those integrators to ground. However, as soon as one or the other of the light sensors 102 and 104 "sees" a line or a colored area on a document 53, the signal at the upper output of the gate generator 524 in FIG. 15 will disappear; and then the capacitors 864 of the various integrators of the Integrators blocks 313 and 603 of FIGS. 19A and 19B will be able to accept and store signals.

The Comparator Reference Selector block 315 in FIG. 19A has the outputs of all of the integrators of the Integrators block 313 connected to the inputs of the OR gate 299 thereof; and that OR gate will respond to the most valid signal received from the outputs of those integrators to apply a signal to the lower input of the differential amplifier 692. That differential amplifier is biased to develop a signal at the output thereof which is slightly below the value of the signal at the lower input thereof; and that differential amplifier applies the output signal thereof to the lower inputs of all of the amplitude comparators 698, 700, 702, 704, 706, 708, 710, 712, 714 and 716 of the Amplitude Comparators block 317 of FIG. 19A. Each of those amplitude comparators will develop a signal at the output thereof whenever the signal applied to the upper input thereof is greater than the signal applied to the lower input thereof; and the outputs of those amplitude comparators are connected to the upper inputs of the AND gates 752, 754, 756, 758, 760, 762, 764, 766, 768 and 770 of the AND gates block 320 in FIG. 19A, and also to the input of the operational amplifier 718 of the Validity Comparator block 322 of FIG. 19A. The diode 750 of that operational amplifier will keep a negative signal from ever developing at the output of that operational amplifier; and the Zener diode 744 and the diode

748 of that operational amplifier will permit the gain of that operational amplifier to be high until the voltage at the output of that operational amplifier is positive and exceeds the Zener value of the Zener diode 744, and will then keep that output voltage from exceeding that Zener voltage. The source of negative biasing voltage, to which the terminal 721 is connected, will apply a negative bias to the input of operational amplifier 718 which is about $1\frac{1}{2}$ times the value of the maximum anticipated positive signal from any of the amplitude comparators of the Amplitude Comparators block 317; and that operational amplifier will respond to a negative voltage at the input thereof to develop a positive voltage at the output thereof. The overall result is that the output of the operational amplifier 718 will be positive and will be clamped at the Zener voltage whenever none or just one of the amplitude comparators of the Amplitude Comparators block 317 is developing a signal at the output thereof, and that the output of that operational amplifier will be clamped at zero whenever two or more of the amplitude comparators of the Amplitude Comparators block 317 are developing signals at the outputs thereof. The integrators of the Integrators block 608, the Comparator Reference Selector block 612, the amplitude comparators of the Amplitude Comparators block 616, and the Validity Comparator block 626 of FIG. 19B will operate in the same manner in which the corresponding elements and blocks of FIG. 19A operate.

As long as both of the light sensors 102 and 104 "see" the base material of a document 53, the signal from the upper output of the gate generator 524 of FIG. 15 will keep the capacitors 864 of all of the integrators in the Integrators blocks 313 and 608 discharged; and hence the signals at the outputs of those integrators—and thus at the upper inputs of the amplitude comparators of the Amplitude Comparators block 317—will be zero. Because the operational amplifier 692 of the Comparator Reference Selector block 315 applies a signal to the lower inputs of the amplitude comparators of the Amplitude Comparators block 317 which is slightly below the value of the signal applied to the input of that operational amplifier by the OR gate 299, each of those amplitude comparators will have a zero signal at the upper input thereof and will have a minus signal at the lower input thereof, and hence all of those amplitude comparators will develop signals at the outputs thereof. Those signals will be applied to the upper inputs of the AND gates of the AND Gates block 320, and also will be applied to the input of the operational amplifier 718 of the Validity Comparator 322 of FIG. 19A. Because that operational amplifier can develop a positive voltage at the output thereof only when it has a negative voltage at the input thereof, and because the application of signals from two or more of the amplitude comparators of the Amplitude Comparators block 317 will make the voltage at the input of that operational amplifier positive, the 0 voltages at the outputs of the integrators of the Integrators block 313—and the consequent signals at the outputs of the amplitude comparators of the Amplitude Comparators block 317—will keep a signal from being applied to the lower inputs of all of the AND gates of the AND Gates block 320 in FIG. 19A and thus will keep all of those AND gates from developing a signal at the outputs thereof. Similarly, the voltages at the outputs of the integrators of the Integrators block 608 of FIG. 19B will be zero when both light sensors 102 and 104 "see" the base material of a document 53; and those 0 voltages—and the consequent signals at the outputs of the amplitude comparators of the Amplitude Comparators block 616 of FIG. 19B—will keep a signal from being applied to the lower inputs of all of the AND gates of the AND Gates block 622 of FIG. 19B and thus will keep all of those AND gates from developing a signal at the outputs thereof. Consequently, as long as both light sensors 102 and 104 "see" the base material of a document 53, the circuits of FIGS. 19A and 19B will not supply a signal to the Digital Code Generator block 556 of FIG. 4.

Whenever both of the light sensors 102 and 104 "see" a line or a colored area on a document 53, the signal at the upper

output of the gate generator 524 in FIG. 15 will disappear. At that time, the capacitors in the various integrators of Integrators blocks 313 and 608 of FIGS. 19A and 19B will be able to receive and store signals; and, every 5 microseconds, one of the word comparators in FIG. 17 will coact with one of the flip-flops in the Gate Generator block 308 and with one of the AND gates of the Coincidence Circuits block 309 of FIG. 19A and with a positive-going zero crossing signal from the Hue Zero Crossing Detector block 302 and the Monostable Multivibrator block 306 in FIG. 12 to apply a signal to one of the integrators in the Integrators block 313 in FIG. 19A. Similarly, one of the word comparators in FIG. 16 will coact with one of the flip-flops in the Gate Generator block 600 and with one of the AND gates in the Coincidence Circuits block 602 of FIG. 19B and with a positive-going zero crossing signal from the Hue Zero Crossing Detector block 302 and the Monostable Multivibrator block 306 in FIG. 12 to apply a signal to one of the integrators in the Integrators block 608 in FIG. 19B. Noise and transient signals may be applied to one or more of the other integrators in the Integrators block 313, and noise and transient signals may be applied to one or more of the other integrators in the Integrators block 608; but noise and transient signals will not have both the amplitude and the repetition rates of the signals from the Coincidence Circuits blocks 309 and 602, and thus will not be able to develop voltages across the capacitors of those one or more other integrators of the Integrators blocks 313 and 608 which can equal or exceed the voltages at the outputs of the integrators which are receiving signals from the Coincidence Circuits blocks 309 and 602 of FIGS. 19A and 19B. This means that at any given instant when both of the light sensors 102 and 104 "see" a line or a colored area on a document 53, one of the integrators of the Integrators block 313 in FIG. 19A will be developing a signal at the output thereof which is larger than the signals at the outputs of all of the other integrators of that Integrators block, and the OR gate 299 of the Comparator Reference Selector block 315 will respond to that larger signal to apply a slightly-smaller signal to the lower inputs of all of the amplitude comparators of the Amplitude Comparators block 317. For purposes of illustration, it will be assumed that the signal at the output of integrator 672—and thus at the input of amplitude comparator 700 of FIG. 19A—is greater than the signal at the output of any other integrator of the Integrators block 313—and thus greater than the signal at the input of any other amplitude comparator of the Amplitude Comparators block 317; and, at such time, the slightly-smaller signal which the Comparator Reference Selector block 315 is applying to the lower inputs of the amplitude comparators of the Amplitude Comparators block 317 will keep all of those amplitude comparators, other than the amplitude comparator 700, from developing signals at the outputs thereof. The signal at the output of amplitude comparator 700 will be applied to the upper input of AND gate 754 and to the input of the operational amplifier 718 of the Validity Comparator block 322 of FIG. 19A. While that signal will make the voltage at the input of that operational amplifier less negative, that voltage will still be negative; and hence that operational amplifier will apply a signal to the lower input of AND gate 754 and to the lower inputs of all of the other AND gates of AND Gates block 320. Because only the amplitude comparator 700 was able to develop a signal at the output thereof, only the AND gate 754 will be able to develop a signal at the output thereof. Similarly, at any given instant when both of the light sensors 102 and 104 "see" a line or a colored area on a document 53, one of the integrators of the Integrators block 608 in FIG. 19B will be developing a signal at the output thereof which is larger than the signals at the outputs of all of the other integrators of that Integrators block, and the OR gate 802 of the Comparator Reference Selector block 612 will respond to that larger signal to apply a slightly smaller signal to the lower inputs of all of the amplitude comparators of the Amplitude Comparator block 616. For purposes of illustration, it will be assumed that the signal at the output of integrator 794—and thus at the input of am-

plitude comparator 810 in FIG. 19B—is greater than the signal at the output of any other integrator of the Integrators block 608—and thus greater than the signal at the input of any other amplitude comparator of the Amplitude Comparators block 616; and, at such time, the slightly-smaller signal which the Comparator Reference Selector block 612 is applying to the lower inputs of the amplitude comparators of the Amplitude Comparators block 616—and thus at the input of amplitude comparator 810—will keep all of those amplitude comparators, after that amplitude comparators 810, from developing signals at the outputs thereof. The signal at the output of amplitude comparator 810 will be applied to the upper input of AND gate 846 and to the input of the operational amplifier 818 of the Validity Comparator block 626 in FIG. 19B. While that signal will make the voltage at the input of that operational amplifier less negative, that voltage will still be negative; and hence that operational amplifier will apply a signal to the lower input of AND gate 846 and to the lower inputs of all of the other AND gates of AND Gates block 622. Because only the amplitude comparator 810 was able to develop a signal at the output thereof, only the AND gate 846 will be able to develop a signal at the output thereof. The overall result is that at any given instant when both of the light sensors 102 and 104 “see” a line or a colored area on a document 53, only one of the AND gates of the AND Gates block 320 and only one of the AND gates of the AND Gates block 622 will develop signals at the outputs thereof.

The Integrators block 313 and the Comparator Reference Selector block 315 in FIG. 19A are important in keeping noise and transient signals from supplying, to the input terminals of the amplitude comparators of the Amplitude Comparators block 317, signals which could cause one or more of those amplitude comparators to develop a signal at the output thereof. That Integrators block also is important in responding only to signals received from the Coincidence Circuits block 309 during the time the light sensors 102 and 104 “see” a pigmented line or area—that Integrators block grounding all signals stored within it prior to “seeing” pigmented areas, and thus keeping previously developed signals from causing undesired signals to appear at the outputs of that Integrators block. Similarly, the Integrators block 608 and the Comparator Reference Selector block 612 in FIG. 19B are important in keeping noise and transient signals from supplying, to the input terminals of the amplitude comparators of the Amplitude Comparators block 616, signals which could cause one or more of those amplitude comparators to develop a signal at the output thereof. That Integrators block also is important in responding only to signals received from the Coincidence Circuits block 309 during the time the light sensors 102 or 104 “see” a pigmented line or area—that Integrators block grounding all signals stored within it prior to “seeing” pigmented areas, and thus keeping previously-developed signals from causing undesired signals to appear at the outputs of that Integrators block.

The Amplitude Comparators block 317 and the Validity Comparator block 322 of FIG. 19A are important in keeping the AND Gates block 320 from developing a signal at any of the outputs thereof in the event more than one of the amplitude comparators of that Amplitude Comparators block develop signals at the outputs thereof; because any signal developed at any of the outputs of that AND Gates block at such time would be a misleading signal. Similarly, the Amplitude Comparators block 616 and the Validity Comparator block 626 of FIG. 19B are important in keeping the AND Gates block 622 from developing a signal at any of the outputs thereof in the event more than one of the amplitude comparators of that Amplitude Comparators block develop signals at the outputs thereof; because any signal developed at any of the outputs of that AND Gates block at such time would be a misleading signal.

When the light sensor 102 “sees” one colored area on a document 53 and the light sensor 104 “sees” a different colored area on that document, the signal developed by the

light sensor 102 will have a positive-going zero crossing that may be different from the positive-going zero crossing of the signal developed by the light sensor 104. The Schmitt trigger of the Hue Zero Crossing Detector 302 of FIG. 12 will respond to whichever of those positive-going zero crossings occurs first, during any given cycle of the counter 246; and, if that Schmitt trigger resets itself before the second of those positive-going zero crossings occurred, that Schmitt trigger also would respond to that second positive-going zero crossing. Whenever the Schmitt trigger of the Hue Zero Crossing Detector 302 of FIG. 12 responds to two positive-going zero crossings during any cycle of the counter 246, two AND gates of the Coincidence Circuits block 309, two integrators of the Integrators block 313, and two amplitude comparators of the Amplitude Comparators block 317 of FIG. 19A will develop signals at the outputs thereof; and, similarly, two AND gates of the Coincidence Circuits block 602, two integrators of the Integrators block 608, and two amplitude comparators of the Amplitude Comparators block 616 of FIG. 19B will develop signals at the outputs thereof. The resulting two signals applied to the input of the operational amplifier 718 of the Validity Comparator block 322 of FIG. 19A will make the voltage at the input of that operational amplifier positive—and thus will make the voltage at the output of that operational amplifier zero; and, similarly, the resulting two signals applied to the input of the operational amplifier 818 of the Validity Comparator block 626 in FIG. 19B will make the voltage at the input of that operational amplifier positive—and thus will make the voltage at the output of that operational amplifier zero. Consequently, the lower inputs of the AND gates of AND Gates block 320 of FIG. 19A and the lower inputs of the AND gates of AND Gates block 622 of FIG. 19B will not receive signals; and hence no signals will be applied to the Digital Code Generator block 556 by the Hue Comparator block 300. This is desirable because any signals developed by that Hue Comparator block, when any two AND gates of the Coincidence Circuits block 309 of FIG. 19A or when any two AND gates of the Coincidence Circuits block 602 of FIG. 19B simultaneously developed signals, would be misleading signals.

G. Operation of Hue Balance Control Block

The light sources 64, 66 and 68 of FIG. 3 are intended to supply values of light to the spot 90 of light which will enable the red component, the blue component, and the green component of the light reflected from the base material of a document 53 to have equal intensities; and, where that occurs, the light reflected from that base material will be white and will develop the DC signal indicated by the line 1040 in FIG. 23 if the light sensors 102 and 104 have flat spectral responses. If a portion of the base material has changed color because of prolonged exposure to the sun, or if one of the light sources 64, 66 and 68 has changed the intensity of the light which it supplies to the spot 90 of light, one or more of the waveforms 1,042, 1,044 and 1,046 in FIG. 23 will experience a change in amplitude. For purposes of illustration, it will be assumed that a change in the intensity of the light from the light source 66 has decreased the amplitude of the blue light waveform 1044, as indicated by dotted lines in FIG. 23, and that a resulting ripple 1,051 has appeared on the DC line 1,040. The filter and the summing network in the Hue Zero Crossing Detector block 302 of FIG. 12 will filter and sum the ripple developed by the light sensors 102 and 104 as those light sensors “see” the base material of the document 53; and the filtered and summed ripple will be applied to the inputs of the phase sensitive detectors 269 and 278 of FIG. 9 by the conductor 304; and also will be applied to the Schmitt trigger of that Hue Zero Crossing Detector block. That Schmitt trigger will not respond to the filtered and summed ripple which the light sensors 102 and 104 develop as they “see” the base material, because that filtered and summed ripple will not have sufficient amplitude to exceed the threshold level of that Schmitt trigger; but the phase sensitive detectors 269 and 278 will respond to that filtered and summed ripple.

The phase sensitive detector 278 will respond to that filtered and summed ripple to apply a signal to the left-hand input of the gate 286; and each time the light sensors 102 and 104 "see" the base material of the document 53, the upper output of the gate generator 524 in FIG. 15 will apply a signal to the upper input 287 of gate 286 which will enable that gate to apply the signal at the output of the phase sensitive detector 278 to the 1,040 290. That integrator will quickly develop a signal and apply it to the lamp driver 294; and that lamp driver will then cause the light source 66 to increase the intensity of the blue light reflected from the base material of document 53 until that intensity again equals the intensity of the red light and of the green light reflected from that base material. Similarly, if a change occurs in the amplitude of the red light reflected from the base material of the document 53, the phase sensitive detector 269 will sense the resulting ripple on the DC line 1040 and will respond to that ripple to apply a signal to the gate 282. Each time the light sensors 102 and 104 "see" the base material of the document 53, the upper output of the gate generator 524 in FIG. 15 will apply a signal to the upper input 284 of gate 282 which will enable that gate to apply the signal at the output of the phase sensitive detector 269 to the integrator 288. That integrator will quickly develop a signal and apply it to the lamp driver 292; and that lamp driver will then cause the light source 64 to change the intensity of the red light reflected from the base material of document 53 until that intensity again equals the intensity of blue light and of the green light reflected from that base material.

As indicated by FIG. 23, the red light waveform 1,042, the blue light waveform 1,044, and the green light waveform 1,046 are coextensive in part. The phase sensitive detector 269 is designed not to respond to the ripple 1,051—although such design is not optimized for response to ripple caused by red light variations; and the phase sensitive detector 278 is designed not to respond to any ripple caused by changes in the red light reflected from the base material of the document 53—although such design is not optimized for response to ripple caused by blue light variations. Both of the phase sensitive detector 269 and 278 will sense and respond to any ripple caused by changes in the green light reflected from the base material of the document 53; and the resulting adjustments in the intensities of the light from the light sources 64 and 66 will again make the light reflected from the base material essentially white. As a result, just the two phase sensitive detectors 269 and 278, just the two gates 282 and 286, just the two integrators 288 and 290, and just the two lamp drivers 292 and 294 of the Hue Balance Control block 274 are needed to keep the light reflected from the base material essentially white.

The phase sensitive detectors 269 and 278 will sense and respond to the AC waveforms which the light sensors 102 and 104 develop as they "see" the lines and the colored areas on the document 53; but the signals which those phase sensitive detectors develop as those light sensors "see" those lines and colored areas will be blocked by the gates 282 and 286—those gates applying signals from those phase sensitive detectors to the integrators 288 and 290 only when the light sensors 102 and 104 "see" the base material of the document 53. Consequently, only those signals which the phase sensitive detectors 269 and 278 develop as the light sensors "see" the base material of a document 53 will be applied to the integrators 288 and 290; but those light sensors will "see" that base material at least once during every revolution of the drum 52 of FIG. 3, and hence the signals from those phase sensitive detectors will quickly develop voltages across the integrators 288 and 290 that will enable the lamp drivers 292 and 294 to appropriately adjust the intensities of the light from the light sources 64 and 66.

The base material of a document 53 will be white more often than not; but the Hue Balance Control block 274 of FIG. 9 will be able to make the light reflected from base materials essentially white even though those base materials are colored. Where a base material of a document 53 is not white, the scanner 60 of FIG. 3 will be shifted until the spot 90 of

light is on that base material; and then the push button switch 528 in FIG. 15 will be pressed—all as explained in the Programming of Color Identification Unit section hereof. While that push button switch is being pressed, the upper output of the gate generator 524 in FIG. 15 will continuously apply a signal to the upper inputs 284 and 287, respectively, of the gates 282 and 286; and hence those gates will enable the phase sensitive detectors 269 and 276 to freely apply signals to the integrators 288 and 290. Those phase sensitive detectors will apply signals to those integrators, and those integrators will supply signals to the lamp drivers 292 and 294 which will progressively but rapidly change the intensities of the light sources 64 and 66 to reduce the amplitude of the ripple on the DC line 1,040 in FIG. 23. When that ripple is effectively eliminated, the light reflected from the base material of the document 53 will be essentially white and the push button switch 528 can be released; and the Hue Balance Control block 274 will thereafter keep that light essentially white. That essentially white light is important, because it enables the color identification unit to sense relative rather than absolute values of hue lightness and the saturation of the pigments used in forming the lines and colored areas on a document 53.

If the light sensors 102 and 104 are not equally sensitive to blue, green and red light, and are more sensitive to blue and green light and less sensitive to red light, a ripple will appear on the conductor 304 even though the light reflected from the base material appears essentially white. This ripple will coast with the phase detector 269, gate 282, integrator 288 and lamp driver 292 to cause the intensity of the light source 64 to increase until the ripple no longer exists. The increased intensity of the light source 64 will increase the intensity of the red light in the spot 90 of light and thus overcome the lower red light sensitivity characteristics of the light sensors 102 and 104; and in effect, the color identification unit will operate in the same manner as though the light reflected from the base material was essentially white and the light sensors had a flat spectral response. It is desirable to minimize the differences in light intensities of the three light sources 64, 66 and 68; and, therefore, it is desirable to use light sensors which have spectral responses which are flat throughout the spectrum. Compensation for nonuniform spectral responses can be accomplished by using colored filters in conjunction with the light sensors 102 and 104, as will be apparent to those skilled in the art. Although a gross nonuniformity of the spectral responses of the sensors 102 and 104 can be compensated for by the use of appropriately colored filters, it is impractical to achieve adequate compensation by using filters; and it is, therefore, important that the Hue Balance Control block 274 compensate for any nonuniform spectral responses of the light sensors 102 and 104.

The sensing of two areas which are located transversely to the direction of scanning is quite important, where a document has large numbers of small dots encoded thereon and where the position of those dots must be determined and where the lightness or contrast of those dots also must be determined. The information obtained by sensing such a document could be accurate and meaningful only when that information was taken as the scanning spot and a "data" dot were aligned. The transversely-located areas sensed by the scanning spots would indicate the exact moment when the scanning spot and "data" dot were aligned.

ALTERNATE CONSTRUCTIONS

In the color identification unit shown in the drawing, the Buffer And Data Record Control block 580 and the Recorder block 582 of FIG. 4 represent sections of a digital computer of standard and usual design; and the Computer Buffer block 570 of FIG. 14 will receive information from the Drum And Scanner Drive block 115, from the Line Sensing block 460, and from the Color Number Decode Matrix block 564 and will hold that information until that digital computer is ready to accept and record it. That information will include the

coordinates of the area being scanned at any instant, and indication of whether that area is on the base material or on a line or on a colored area, and a digital number identifying the pigment used to form the line or area on the document being scanned; but the Line Sensing block 460 will supply information to the Computer Buffer block 570 only when the signal from the area 960 in FIGS. 33, 39, 45 and 51 is very similar to the delayed signal corresponding to the area 964 and when the signal from the area 962 is very similar to the delayed signal corresponding to the area 963. However, if desired, that color identification unit could be modified to enable the Computer Buffer block 570 to receive signals from the Drum And Scanner Drive block 115, from the Line Sensing block 460, and from the Color Number Decode Matrix block 564 at all times. Further, if desired, the color identification unit could be modified to enable the Computer Buffer block 570 to receive signals from the Drum And Scanner Drive block 115, from the Line Sensing block 460, and from the Color Number Decode Matrix block 564 only when predetermined widths of lines or when predetermined pigments were "seen" by the light sensors 102 and 104.

In the color identification unit shown in the drawing, a number of arithmetic functions are performed by various separate and discrete circuits. If desired, that color identification unit could be modified to enable a number of those arithmetic functions to be performed by the digital computer of which the Buffer And Data Record Control block 580 and the Recorder block 582 are sections.

The Wollaston prisms 94 and 100 of FIG. 3 are very useful and desirable. However, if desired, a Rochon prism could be substituted for each of those Wollaston prisms. In addition, a number of glass plates, set at the Brewsterian angle, could be substituted for the Wollaston prism 100.

In FIG. 2, the scanner 60 is disposed adjacent the front of the rotatable drum 52; and such a disposition is desirable because it provides ready access to that scanner, and also permits visual observation of the scanned area of the document 53. However, if desired, the scanner 60 could be mounted directly below the rotatable drum 52 so the axis of that scanner was vertical rather than horizontal. Such an arrangement would provide more complete access to the rotatable drum 52 and would thereby facilitate the securement of a document 53 to, and the removal of that document from, that rotatable drum. Further, such an arrangement would facilitate the enclosing and protecting of the scanner 60.

In the color identification unit, the document 53 is secured to the rotatable drum 52 by a flexible sheet of tough, transparent material. However, if desired, that document could be secured to that drum by edge clamps, or by making the walls of that rotatable drum porous and then maintaining a reduced pressure within the interior of that rotatable drum. In the latter case, the differential between atmospheric pressure and the reduced pressure within the rotatable drum 52 would hold the document 53 tightly against the exterior of that drum.

In the color identification unit shown in the drawing, only two lamp drivers, only two integrators, only two gates, and only two phase sensitive detectors are included in the Phase Detector block 276 of FIG. 9. If desired, a third lamp driver, a third integrator, a third gate, and a third phase sensitive detector could be included in that Phase Detector block. However, a third lamp driver, a third integrator, a third gate, and a third phase sensitive detector are not necessary; because the light source 68 acts as a standard, and the intensities of the light sources 64 and 66 are readily adjusted relative to the intensity of that light source standard to provide the desired essentially white light from the base material of the document 53. While FIG. 9 shows the conductor 271 connected to the phase sensitive detector 269 and shows the conductor 273 connected to the phase sensitive detector 278, any one of the conductors 271, 273 and 275 can be connected to the phase sensitive detector 269 and any one of the other two conductors can be connected to the phase sensitive detector 278; and those phase sensitive detectors could control the appropriate light sources.

The color identification unit is shown in the drawing as it senses light reflected from a document 53 which has an essentially opaque base material with lines and colored areas thereon. However, that color identification unit can also be used to sense a document, such as a photographic film, which is transparent or translucent in parts—an opaque sheet being secured to the rotatable drum 52 beneath that document to reflect light toward the lens system 92 in FIG. 3. Such an opaque sheet would enable the color identification unit to sense reflected light, and thus permit "reading" of transparent as well as essentially opaque documents. Although "reading" of transparent documents by transmitted light provides a good signal-to-noise ratio, the reading of essentially opaque documents by transmitted light provides a poor signal-to-noise ratio.

In the color identification unit shown in the drawing, the Wollaston prism 94 is shown about midway between the lens system 92 and the aperture plate 96; and the Wollaston prism 100 is shown about midway between that aperture plate and the light sensors 102 and 104. If desired, the Wollaston prism 94 could be moved closer to the lens system 92 to increase the relative displacement of the spots 101 and 105 of light formed on the aperture plate 96; or that Wollaston prism could be moved closer to that aperture plate to reduce the relative displacement of those spots of light. Similarly, the Wollaston prism 100 could be moved closer to the aperture plate 96 to increase the spacing between the displaced spots of light formed thereby, or it could be moved further away from that aperture plate to decrease the spacing between those spots of light. As a result, any desired displacement of the spots 101 and 105 of light can be attained, and any desired displacement of the inputs of the light sensors 102 and 104 can be attained.

In the color identification unit shown in the drawing, the scanning of the document 53 is effected by developing the spot 90 of light at a fixed point and that rotating and translating the rotatable drum 52 and the document 53 thereon relative to that point. If desired, a cathode ray tube could be used to generate a scanning spot which could scan a translucent or transparent document, such as a photographic film. In such event, a Wollaston prism or the like would be interposed between the face of the cathode ray tube and the photographic film, and a second Wollaston prism or the like would be interposed between that photographic film and the inputs of the light sensors 102 and 104. Suitable lens systems would be associated with the Wollaston prisms—one of those lens systems being disposed between the face of the cathode ray tube and the adjacent Wollaston prism to image the scanning spot of that cathode ray tube onto the photographic film; and a field lens being disposed between that photographic film and the second Wollaston prism to collect the light transmitted through that photographic film. The two Wollaston prisms would doubly orthogonally-polarize the light, so one of the light sensors would "see" one area on the photographic film while the other of those light sensors would "see" a displaced area on that photographic film.

The signals developed by the light sensors 102 and 104 can be used as described herein for line sensing, and also may be used to develop "tracking signals" which, when applied to cathode ray tube deflection circuits, will provide an automatic tracking of a line which is essentially, but not precisely, aligned in the direction of scan.

Similarly, an electromechanical tracking system may use an optical system of the configuration shown in FIG. 3. The sensors 102 and 104 would develop signals which would indicate the location of two spots with respect to a line; and those signals, in turn, would provide positioning signals to position the document with respect to the optical system, so the line being "tracked" would be located between the two spots. The Wollaston 182 prisms 94 and 100 and the light sensors 102 and 104 could be rotatable about the optical axis of the lens system 92 to maintain the two orthogonally polarized "spots" transverse to the direction of motion along the line being tracked. The tracking system would thus be capable of following a line in any direction, and would develop signals to follow

any curving line. The illumination of the spot 90 of light could be generated as shown in FIG. 3; and the contrast signals, or more conventional illumination techniques, could be used to track a line using a more conventional technique of lightness difference sensing.

Different scanning speeds for the color identification unit can be attained by using larger or smaller rotatable drums 52. Different scanning speeds also can be attained by using different gear ratios between the rotatable drum 52 and the lead screw 58 in FIG. 2.

The signals which appear at the junctions 474, 476, 494 and 496 in FIG. 15 represent the contrast of the four spots 960, 964, 962 and 963 of FIG. 33, respectively, relative to the contrast of the base material of the document 53. If desired, the circuit of FIG. 15 could be connected to receive signals corresponding to relative lightness or to some other parameter; and, in such event, the signals appearing at the junctions 474, 476, 494 and 496 in FIG. 15 would represent the relative lightness or that other parameter.

The circuit of FIG. 15 develops a signal at the output of AND gate 522 which corresponds to the sum of the signals at the junctions 474 and 476 or to the sum of the signals at the junctions 494 and 496. Further, the circuit of FIG. 15 generates a signal which corresponds to the absolute value of the difference between the signals at the junctions 474 and 476 or to the absolute value of the difference between the signals at the junctions 494 and 496. While the circuit of FIG. 15 is very useful and desirable, other circuits could be used which would provide the signals provided by the circuit of FIG. 15.

If desired, the circuit of FIG. 15 could be modified by substituting a sum amplifier for the AND gate 522; and, in such event, the signal which that sum amplifier would supply to the gate generator 524 would be the sum of the signals corresponding to the four spots 960, 964, 962 and 963 of FIG. 33. Further, if desired, the circuit of FIG. 15 could be modified to generate a signal proportional to the part of the document 53 represented by the spot 960 or the spot 962 or the spot 963 or the spot 964 of FIG. 33; and that modified circuit would apply that signal to the gate generator 524. In both of these modifications of the circuit of FIG. 15, a signal would be applied to the gate generator 524 whenever one of the spots 960, 962, 963 and 964 of FIG. 33 represented an area on the document 53 which was sufficiently pigmented to develop a signal equal to or greater than a predetermined value.

The circuit of FIG. 15 determines when the spots 960, 962, 963 and 964 of the array of spots of FIG. 33 are wholly within an area, such as an area on the base material or an area within a pigmented portion of the document 53, or when the center of that array of spots is centered on a line; and that circuit accomplishes that result by generating and applying to the input of gate generator 548 a signal which is zero when the signals corresponding to the difference between both pairs of diagonally-disposed spots are zero. However, if desired, the circuit of FIG. 15 could be modified to enable it to sum the signals corresponding to the spots 960 and 962 and to sum the signals corresponding to the spots 963 and 964 and then to determine the absolute value of the difference between those sums, and also to sum the signals corresponding to the spots 962 and 964 and to sum the signals corresponding to the spots 960 and 963 and then to determine the absolute value of the difference between the latter two sums. Whenever both of the difference signals of such a modification of FIG. 15 were zero, the array of spots would be entirely within an area or would be located at the center of a line.

Further, if desired the circuit of FIG. 15 could be modified to enable it to be used in a "tracking" system, wherein the overlapping portions of the spots 960 and 962 were intended to lie on the center of a line parallel to the direction of scan. In such event, the circuit of FIG. 15 would be modified to provide a signal which was proportional to the difference between the signals corresponding to the spots 960 and 962 of FIG. 33; and that signal would indicate whenever the overlapping por-

tions of the spots 960 and 962 were above the center of the line being tracked or were below the center of that line, and thus would provide a signal which would enable the "tracking" system to reposition the spots 960 and 962 so those overlapping portions would again lie on the center of the line being tracked.

CONCLUSION

The color identification unit provided by the present invention can set the boundaries of the "angle slots" of the polar coordinate graphs of FIGS. 29 and 31 at any one of one hundred and twenty equally-spaced points, and hence can set any of those boundaries to within $1\frac{1}{2}$ of any desired angular position. Similarly, that color identification unit can set the leading and trailing edges of the square waves 950, 952 and 954 of FIG. 22 at any one of one hundred and twenty equally-spaced points, and hence can set any of those edges to within $1\frac{1}{2}$ of any desired position. As a result, that color identification unit can provide a desirably effective identification of the pigments used to form the various colored areas on the document 53.

The color identification unit shown in the drawing utilizes the "angle slots" provided by the circuits of FIGS. 16 and 17 in determining the longitude angles of the pigments "seen" by the light sensors 102 and 104. Such an arrangement is far superior to any arrangement wherein differences in voltage are utilized to determine the longitude angle of pigments "seen" by the light sensors 102 and 104, because angular differences can be more distinctive than voltage differences.

The identification of a pigment by measuring the longitude and latitude characteristics of the light reflected from a pigmented area, as defined herein, is important because it provides positive identification of that pigment independent of variations of pigmentation, and independent of variations in the percentage of base material versus pigmented area "seen" by the light sensor.

The detection of a pigmented area using the contrast characteristics, as defined herein, is important because it provides a data extraction capability which will "sense" the presence of any color. A fully chromatic sensing system which detects only variations of total energy, may be "blind" to such colors as yellow which reflects more red and green light than the base material, and which absorbs only blue light. The total energy reflected by such a color may have the same lightness as the base material, and a fully chromatic sensor would detect no change of lightness. A monochromatic detector which senses only blue light would easily detect such a yellow color; but such a monochromatic detector would not sense a blue color. The contrast signal generated as described herein, provides the capability of sensing any color which is distinctly different from the base material, whether that difference is lightness alone, saturation alone, or both saturation and lightness.

The use of modulated light is important, because only modulated light will develop the signals which are used to determine the color characteristics printed on the document. Reasonable levels of ambient light will not affect the operation of the color identification unit, and, therefore, that color identification unit may be operated in a lighted area.

The use of modulated light is also important because a sensing system, which under normal unmodulated light, does not have the capability of detecting or measuring color characteristics, is caused to generate a signal which contains usable color information.

The red, blue and green filters 70, 72 and 74 of FIG. 3 will be usable for most documents 53. However, for some documents it may be desirable to replace one or more of those filters by filters which will enable the color identification unit to accommodate special pigments and pigment combinations on the document 53.

The use of just one aperture 98 in the aperture plate 96 is important, because it avoids all of the errors which could occur if two apertures were used and an error was made in the positioning of either of those apertures. Moreover, the use of

just one aperture avoids all of the errors which could arise in the event a speck of dust or other foreign material were to lodge in one of the two apertures in an aperture plate. With just one aperture in the aperture plate, all of the light passing through that one aperture will be affected the same way by the positioning, size or cleanliness of that one aperture.

The sensing of two areas, such as the areas 960 and 962 in FIGS. 33, 39, 45 and 51, which are located transversely of the direction of scanning is important; because the sensing of those two areas enables the color identification unit to determine when a line or the edge of a colored area is parallel to, or is inclined at a shallow angle to, the direction of scanning. The sensing of two areas, which are located transversely of the direction of scanning, also is important because it permits the signals from those two areas to be combined with delayed signals from those areas to enable the color identification unit to determine the locations of the centers of lines on a document 53. The determination of the locations of the centers of lines on a document is particularly important where those lines are drawn rather than printed on the document—the edges of drawn lines frequently being somewhat irregular in nature, and thus being less definitive of the locations of those lines than are the centers of those lines.

The delay circuits 470 and 472 in FIG. 15 are important in developing the simulated areas 964 and 963 of FIGS. 33, 39, 45 and 51; but the phase shifts which those delay circuits create in the signals corresponding to those simulated areas keep those signals from being used to determine the longitude angles of the pigments "seen" by the light sensors 102 and 104. As a result, the signals developed by the circuit of FIG. 15 cannot be used to sense the longitude angles of the pigments "seen" by the lights sensors 102 and 104; but the color identification unit shown in the drawing fully and precisely determines those longitude angles by means of the Hue Reference Generator block 230, the Hue Comparator block 300, the Latitude Comparator block 330, the Color Contrast And Latitude Computer block 366, and the Digital Code Generator block 556 of FIG. 4.

Whereas the drawing and accompanying description have shown and described a preferred embodiment of the present invention it should be apparent to those skilled in the art that various changes may be made in the form of the invention without affecting the scope thereof.

I claim:

1. The method of identifying a pigment used in preparing a document that comprises:
 - determining the hue of said pigment relative to the hue of the base material of said document;
 - determining the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base material of said document with respect to said black end of said locus of achromatic light of said color solid;
 - determining the saturation of said pigment relative to the saturation of said base material of said document; and
 - using the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment.
2. The method of identifying a pigment as claimed in claim 1 wherein said document is scanned by a spot of light composed of a plurality of chromatically-different spots of light.
3. The method of identifying a pigment as claimed in claim 1 wherein said document is scanned by a spot of light composed of a plurality of chromatically-different spots of light and wherein the intensities of said chromatically-different spots of light are modulated.
4. The method of identifying a pigment used in preparing a document that comprises:
 - determining the hue of said pigment relative to the hue of the base material of said document;
 - determining the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base material of said docu-

- ment with respect to said black end of said locus of achromatic light of said color solid;
 - determining the saturation of said pigment relative to the saturation of said base material of said document;
 - using the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment;
 - scanning said document by a spot of light composed of a plurality of chromatically-different spots of light; and
 - setting the intensities of said chromatically-different spots of light to cause the light received from said base material to be essentially white.
5. The method of identifying a pigment used in preparing a document that comprises:
 - determining the hue of said pigment relative to the hue of the base material of said document;
 - determining the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base material of said document with respect to said black end of said locus of achromatic light of said color solid;
 - determining the saturation of said pigment relative to the saturation of said base material of said document;
 - using the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment;
 - scanning said document by a spot of light composed of a plurality of chromatically-different spots of light;
 - setting the intensities of said chromatically-different spots of light to cause the light received from said base material to develop a DC signal as long as said received light is essentially white light and to create a ripple on said DC signal whenever said received light is not essentially white; and
 - said ripple being used to adjust the intensity of at least one of said chromatically-different spots of light.
 6. The method of identifying a pigment used in preparing a document that comprises:
 - determining the longitude angle of said pigment within a color solid;
 - determining a value corresponding to the position of said pigment with respect to the black end of the locus of achromatic light of said color solid;
 - determining a value corresponding to the contrast of said pigment;
 - using the first said value and said second value to obtain a third value corresponding to the cosine of the latitude angle of said pigment within said color solid; and
 - using said longitude angle and said cosine of said latitude angle to identify said pigment.
 7. The method of identifying a pigment as claimed in claim 6 wherein the first said value is the square of said position of said pigment along said achromatic locus, wherein said second value is the square of the contrast of said pigment, and wherein said third value is the square of said cosine of said latitude angle.
 8. A color identification unit that comprises:
 - a light source that can direct light onto a document;
 - a light sensor that can receive light from said document;
 - said light sensor developing an essentially DC signal in response to light received from the base material of said document and developing an essentially AC signal in response to light received from a colored area on said document, said essentially AC signal developed by said light sensor including information on the position of the pigment used in preparing said colored area with respect to the black end of the locus of achromatic light of a color solid;
 - a first circuit that responds to signals developed by said light sensor to provide a signal which is a measure of the latitude angle of said pigment within said color solid; and
 - a second circuit that responds to signals developed by said light sensor to provide a signal which is a measure of the hue of said pigment.

9. A color identification unit as claimed in claim 8 wherein said first circuit has a subcircuit which determines a value corresponding to said position of said pigment along said achromatic locus, wherein said first circuit has a second subcircuit which determines a second value corresponding to the contrast of said pigment, and wherein said first circuit has a third subcircuit which combines the first said and said second values to develop said signal which is a measure of said latitude angle.

10. A color identification unit that comprises:

a light source that can direct light onto a document;

a light sensor that can receive light from said document;

said light sensor developing an essentially DC signal in response to light received from the base material of said document and developing an essentially AC signal in response to light received from a colored area on said document, said essentially AC signal developed by said light sensor including information on the position of the pigment used in preparing said colored area with respect to the black end of the locus of achromatic light of a color solid;

a first circuit that responds to signals developed by said light sensor to provide a signal which is a measure of the latitude angle of said pigment within said color solid;

said first circuit having a subcircuit which includes a squaring circuit and a low frequency filter that coact to provide a value corresponding to said position of said pigment along said achromatic locus;

said first circuit having a second subcircuit which includes said squaring circuit and a delay circuit and a rejection filter that coact to provide a second value corresponding to the contrast of said pigment; and

said first circuit having a third subcircuit which combines the first said and said second values to develop said signal which is a measure of said latitude angle.

11. A color identification unit that comprises:

a light source that can direct light onto a document;

a light sensor that can receive light from said document;

said light sensor developing an essentially DC signal in response to light received from the base material of said document and developing an essentially AC signal in response to light received from a colored area on said document, said essentially AC signal developed by said light sensor including information on the position of the pigment used in preparing said colored area with respect to the black end of the locus of achromatic light of a color solid;

a first circuit that responds to signals developed by said light sensor to provide a signal which is a measure of the latitude angle of said pigment within said color solid;

said first circuit having a subcircuit which determines a value corresponding to said position of said pigment along said achromatic locus;

said first circuit having a second subcircuit which includes a squaring circuit and a delay circuit and a rejection filter that coact to provide a second value corresponding to the contrast of said pigment;

said first circuit having a third subcircuit which combines the first said and said second values to develop said signal which is a measure of said latitude angle;

said light from said light source being modulated at a predetermined frequency; and

said delay circuit providing a time delay equal to one-half of a cycle of said predetermined frequency.

12. A color identification unit as claimed in claim 8 wherein said second circuit senses the phase of said AC signals developed by said light sensor.

13. A color identification unit that comprises:

first means to determine the hue of a pigment on a document relative to the hue of the base material of said document;

second means to determine the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base

material of said document with respect to said black end of said locus of achromatic light of said color solid;

third means to determine the saturation of said pigment relative to the saturation of said base material of said document; and

fourth means responsive to the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment.

14. A color identification unit that comprises:

first means to determine the hue of a pigment on a document relative to the hue of the base material of said document;

second means to determine the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base material of said document with respect to said black end of said locus of achromatic light of said color solid;

third means to determine the saturation of said pigment relative to the saturation of said base material of said document;

fourth means responsive to the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment; and

said first means including a circuit that senses the longitude angle of said pigment within said color solid by sensing zero crossings of signals developed by a light sensor as said light sensor "sees" said pigment.

15. A color identification unit that comprises:

first means to determine the hue of a pigment on a document relative to the hue of the base material of said document;

second means to determine the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base material of said document with respect to said black end of said locus of achromatic light of said color solid;

third means to determine the saturation of said pigment relative to the saturation of said base material of said document;

fourth means responsive to the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment; and

said second means including a circuit which essentially filters out the AC components of the signals developed by a light sensor as said light sensor "sees" said pigment to provide essentially DC values corresponding to said position of said pigment along said achromatic locus.

16. A color identification unit as claimed in claim 13 wherein said third means includes a squaring circuit and a delay circuit and a rejection circuit that coact to provide a signal which is a measure of the contrast of said pigment.

17. A color identification unit as claimed in claim 13 wherein said first means includes a circuit that senses the longitude angle of said pigment within said color solid by sensing zero crossings of signals developed by a light sensor as said light sensor "sees" said pigment, wherein said second means includes a circuit which essentially filters out the AC components of the signals developed by a light sensor as said light sensor "sees" said pigment to provide essentially DC values corresponding to said position of said pigment along said achromatic locus, and wherein said third means includes a squaring circuit and a delay circuit and a rejection circuit that coact to provide a signal which is a measure of the contrast of said pigment.

18. A color identification unit as claimed in claim 13 wherein said document is scanned by a spot of light composed of a plurality of chromatically-different spots of light.

19. A color identification unit as claimed in claim 13 wherein said document is scanned by a spot of light composed of a plurality of chromatically-different spots of light and wherein the intensities of said chromatically-different spots of light are modulated.

20. A color identification unit that comprises:

first means to determine the hue of a pigment on a document relative to the hue of the base material of said document;

second means to determine the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base material of said document with respect to said black end of said locus of achromatic light of said color solid;

third means to determine the saturation of said pigment relative to the saturation of said base material of said document;

fourth means responsive to the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment;

said document being scanned by a spot of light composed of a plurality of chromatically-different spots of light; and the intensities of said chromatically-different spots of light being set to cause the light received from said base material to be essentially white.

21. A color identification unit that comprises:

first means to determine the hue of a pigment on a document relative to the hue of the base material of said document;

second means to determine the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of said base material of said document with respect to said black end of said locus of achromatic light of said color solid;

third means to determine the saturation of said pigment relative to the saturation of said base material of said document;

fourth means responsive to the relative hue, the relative position along said achromatic locus, and the relative saturation of said pigment to identify said pigment;

said document being scanned by a spot of light composed of a plurality of chromatically-different spots of light; the intensities of said chromatically-different spots of light being adapted to cause the light received from said base material to develop a DC signal as long as said received light is essentially white light and to create a ripple on said DC signal whenever said received light is not essentially white; and

a fifth means responding to said ripple to adjust the intensity of at least one of said chromatically-different spots of light.

22. A color identification unit which comprises:

means to provide a plurality of individually-different colors of light;

a light modulator which modulates the intensities of said individually-different colors of light;

an optical system that directs said modulated colors of light toward a document to form a spot of light on said document;

means providing relative movement between said spot of light and said document to cause said spot of light to "scan" portions of said document;

a light sensor that receives light from the areas of said document which are successively illuminated by said spot of light and that responds to said light to develop waveforms; and

means to sense the differences between the waveforms developed by said light sensor as it "sees" a colored area on said document and the waveforms developed by said light sensor as it "sees" the base material of said document.

23. A color identification unit which comprises:

means to provide a plurality of individually-different colors of light;

a light modulator which modulates the intensities of said individually-different colors of light;

an optical system that directs said modulated colors of light toward a document to form a spot of light on said document;

means providing relative movement between said spot of light and said document to cause said spot of light to "scan" portions of said document;

a light sensor that receives light from the areas of said document which are successively illuminated by said spot of light and that responds to said light to develop waveforms; and

means to sense the differences between the waveforms developed by said light sensor as it "sees" a colored area on said document and the waveforms developed by said light sensor as it "sees" the base material of said document; and

said last-mentioned means including a low pass filter that effectively separates the DC components from the AC components of the waveforms developed by said light sensor.

24. A color identification unit as claimed in claim 22 wherein said individually-different colors of light include the basic components of white light so said light sensor will "see" essentially white light as it "sees" the base material of said document.

25. A color identification unit which comprises:

means to provide a plurality of individually-different colors of light;

a light modulator which modulates the intensities of said individually-different colors of light;

an optical system that directs said modulated colors of light toward a document to form a spot of light on said document;

means providing relative movement between said spot of light and said document to cause said spot of light to "scan" portions of said document;

a light sensor that receives light from the areas of said document which are successively illuminated by said spot of light and that responds to said light to develop waveforms;

means to sense the differences between the waveforms developed by said light sensor as it "sees" a colored area on said document and the waveforms developed by said light sensor as it "sees" the base material of said document; and

said light modulator phase displacing the modulated light from said individually-different colors of light.

26. A color identification unit as claimed in claim 22 wherein said light modulator modulates the intensities of the light from said individually-different colors of light, wherein said light modulator phase displaces the modulated light from said individually-different colors of light, and wherein said color identification unit has a circuit which can be programmed to provide different phase displacements of the modulated light from said individually-different colors of light.

27. The method of identifying a pigment used in preparing a document that comprises:

determining the longitude angle of said pigment within a color solid;

determining the latitude angle of said pigment within said color solid; and

using said longitude angle and said latitude angle to identify said pigment.

28. The method of identifying a pigment as claimed in claim 27 wherein an AC waveform is developed as said pigment is "seen," wherein time periods are developed during which zero crossings corresponding to the longitude angles of predetermined pigments are expected to occur, and wherein the time period which is active as said AC waveform crosses zero in a predetermined direction is sensed to determine the longitude angle of said pigment.

29. The method of identifying a pigment that comprises:

determining the longitude angle of said pigment within a color solid;

determining the latitude angle of said pigment within said color solid;

using said longitude angle and said latitude angle to identify said pigment;

sensing the position of said pigment with respect to the black end of the achromatic locus of a color solid;
 sensing the saturation of said pigment;
 using said position of said pigment with respect to said black end of said locus of achromatic light of said color solid and said saturation to determine the contrast of said pigment; and
 using said position of said pigment with respect to said black end of said locus of achromatic light of said color solid and said contrast to determine the latitude angle of said pigment within said color solid.

30. The method of identifying a pigment that comprises:
 determining the longitude angle of said pigment within a color solid;
 determining the latitude angle of said pigment within said color solid;
 using said longitude angle and said latitude angle to identify said pigment;
 sensing the position of said pigment with respect to the black end of the locus of achromatic light of a color solid relative to the position of the base material of the document bearing said pigment with respect to said black end of said locus of achromatic light of said color solid;
 sensing the contrast of said pigment relative to the contrast of said base material; and
 using the relative positions of said pigment and of said base material along said achromatic locus and the relative contrast to determine the latitude angle of said pigment within said color solid.

31. A color identification unit as claimed in claim 8 wherein said light from said light source is modulated at a predetermined frequency, and wherein said second circuit includes means to sense the phase of said essentially AC signal developed by said light sensor relative to the modulation of said light at said predetermined frequency.

32. A color identification unit which comprises:
 a source of light;
 light-modulating means receiving light from said source of light and phase-displacing and amplitude-modulating said light;
 a document-receiving support mounted in the path of the phase-displaced, amplitude-modulated light from said light-modulating means;
 means providing relative movement between said document-receiving support and said phase-displaced, amplitude-modulated light to enable said phase-displaced, amplitude-modulated light to "scan" a document held by said document-receiving support;
 a light-sensor receiving light from said document held by said document-receiving support;
 a circuit connected to said light sensor to analyze information within the light from said document; and
 said phase-displaced, amplitude-modulated light from said light-modulating means being modified by light-absorbing pigments on said document.

33. A color identification unit which comprises:
 a source of light;
 light-modulating means receiving light from said source of light and phase-displacing and amplitude-modulating said light;
 a document receiving support mounted in the path of the phase-displaced, amplitude-modulated light from said light-modulating means;
 means providing relative movement between said document-receiving support and said phase-displaced amplitude-modulated light to enable said phase-displaced, amplitude-modulated light to "scan" a document held by said document-receiving support;
 a light-sensor receiving light from said document held by said document-receiving support;
 a circuit connected to said light sensor to analyze information within the light from said document;
 said phase-displaced, amplitude-modulated light from said light-modulating means being modified by light-absorbing pigments on said document;
 said source of light including three light sources;
 said light-modulating means including three light modulators;
 each of said light modulators being in register with one of said light sources; and
 filters interposed between said light sources and said light modulators.

34. A color identification unit which comprises:
 a source of light;
 light-modulating means receiving light from said source of light and phase-displacing and amplitude-modulating said light;
 a document-receiving support mounted in the path of the phase-displaced, amplitude-modulated light from said light-modulating means;
 means providing relative movement between said document-receiving support and said phase-displaced amplitude-modulated light to enable said phase-displaced, amplitude-modulated light to "scan" a document held by said document-receiving support;
 a light-sensor receiving light from said document held by said document-receiving support;
 a circuit connected to said light sensor to analyze information within the light from said document;
 said phase-displaced, amplitude-modulated light from said light-modulating means being modified by light-absorbing pigments on said document;
 said light sensor developing an AC waveform which has essentially the same frequency and the same phase as a component of said phase-displaced amplitude-modulated light whenever said light sensor "sees" the base material of said document held by said document-receiving support; and
 said circuit sensing shifts of said AC waveform as said light sensor "sees" a pigment of said document.