

PATENT SPECIFICATION

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(54) PROJECTION SCREEN AND METHOD FOR THE FABRICATION THEREOF

(71) We, EASTMAN KODAK COMPANY, a Company organized under the Laws of the State of New Jersey, United States of America of 343 State Street, Rochester, New York 14650, United States of America, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to front and to rear projection screens of the type comprising a plurality of rectilinear rows of optical microelements, each of which is specially contoured to distribute image flux so as to produce substantially constant luminance throughout a predefined solid audience angle. Additionally, the present invention relates to methods for fabricating the screens.

In Patent Specification No. 1,421,138 radiation redistributive devices, such as front and rear projection screens, are disclosed having a light distributing surface which comprises a plurality of rectilinear grooves. The depth of each of the grooves undulates in a periodic manner along the groove length in accordance with a predetermined waveform to define a row of optical microelements which produce substantially uniform radiance throughout a predefined region of utility. That patent specification also discloses an apparatus and a method for fabricating such a projection screen. Briefly, the screen is fabricated by employing the cutting stylus of a sound recording head as a tool for cutting the light distributing surface of the screen and by modulating the cutting position of the stylus with an electrical signal of a predefined waveform. Ideally, the undulation representing the depth profile of each groove should be perfectly in phase with that of all other grooves, since slight changes in phase relationship between optical microelements give rise to

a surface having a streaky appearance. However, since the groove are necessarily cut in a sequential manner, the worm piece from which the projection screen is fabricated being moved past the cutting stylus in a series of equally spaced parallel transverses, it is exceptionally difficult, due to minute variations in the velocity of the work piece, minute variations in the frequency of the signal used to modulate the cutting stylus, and the electro-mechanical transducer delays associated with the mounting structure of the cutting stylus, to maintain the ideal phase relationship from one groove to another. The screen surface may then exhibit random streaks of light and dark areas running parallel to the grooves which are displeasing to the eye. Also, the array of small, uniformly-sized microelements may give rise to diffraction fringes which, in turn, may cause a microelement to appear lighter or darker than it should, depending on the specific point in the audience space from which it is viewed, or even introduce colour where there should be none.

To improve the aesthetic appearance of the screens, Patent Specification No. 1,421,139 discloses that the signal used to modulate the cutting position of the stylus may be intentionally randomized in frequency so as to produce optical microelements of random size but of similar image flux-distributing contour. While showing marked improvement in aesthetic appearance over similar screens comprised of substantially equally sized microelements, such screens may still exhibit some diffraction effects when irradiated (e.g. colour banding) which are somewhat unpleasant to the eye. These diffraction effects are noticeable to the viewer because the frequency the randomized stylus control waveform is changed slowly in order to maintain substantial continuity of waveform slope and therefore light redistribution profile for

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adjacent microelements. Since the distance from a point on one microelement contributing to the appearance of a particular colour to corresponding points on adjacent microelements is substantially equal, the colour banding problem is not eliminated. Colour banding could be further reduced by increasing the frequency of the randomized stylus control waveform. However, if this is done the shape of each microelement would be changed so that the desired uniform light distribution would no longer be obtained.

U.S. Patent Specification No. 3,809,457 discloses an improved screen in which the microelements are randomly sized, at least in one transverse direction, to the extent that the slope of a particular microelement's contour at any point along a row is not predictable from a knowledge of the slope of other microelement contours along the row. The distribution of such randomly sized microelements is predictable, however, to the extent, that, on the average, all reasonably small areas on the screen (i.e., an area which is small compared to the entire area of the screen itself but nevertheless is large compared to the transverse structure defining each microelement) redirect normally incident light into solid audience angles of the same size and shape. Such a screen has improved aesthetic qualities because the random structure causes all small areas on the screen to appear uniformly bright to the viewer. Such a screen is fabricated by applying to the cutting stylus an electrical signal having a waveform which is random at least to the extent that the slope of such waveform is, at any point unpredictable (within a predefined range of slope values) from the knowledge of the slope at other points on the waveform, but is predictable to the extent that the slope probability density profile (i.e., its frequency distribution of slope values) over the irradiated screen area has substantially the same shape as the radiation-redistribution profile desired from that area.

While screens produced according to teachings of U.S. Patent Specification No. 3,809,457 have solved the problem of colour banding, they exhibit a characteristic known as scintillation, which manifests itself as extremely small areas having very high brightness. This characteristic is usually associated with rear projection diffusion type screens.

It is an object of the present invention to provide front and rear projection screen surfaces in which colour bending is substantially reduced or eliminated, without producing scintillation.

In accordance with one aspect of the

present invention there is provided a projection screen of the type having a surface defining a plurality of contiguous grooves, each of the grooves having a depth which undulates along the groove length in accordance with a periodic waveform and thereby defines a row of alternately concave and convex optical microelements which are contoured to redistribute incident radiation uniformly throughout a predefined solid audience angle, wherein both the length and amplitude of the microelements in each row changes at the points corresponding approximately to the completion of each cycle of the said waveform and the amplitude to length ratio of the microelements remains constant, the said length and amplitude changes providing periodic, abrupt changes in the scale of the microelements which vary by a random amount while maintaining substantially identical the absolute value of the slopes of corresponding points on the contours of the microelements.

The said length and amplitude changes may occur at points corresponding approximately to the completion of each half-cycle of the said waveform.

Preferably the microelements in each row have an identical phase relationship with the microelements in adjacent rows.

The objects of the invention are accomplished by employing the cutting stylus of a sound recording head as a tool for cutting a plurality of rows of alternatively concave and convex optical microelements in the screen surface. A control signal which changes both in wavelength and amplitude at the end of each half cycle or full cycle but maintains the amplitude to wavelength ratio constant may be recorded on a memory unit. A suitable memory unit may be stretched between two projections rigidly mounted on an X-Y milling table that supports the blank work piece in which the rows of microelements are to be cut. A pickup head mounted on the base of the sound recording head may be brought into light contact with memory element. As the milling table moves, a signal is generated in the pickup head which is coupled to a control circuit comprising an amplifying means and a band pass filter. From the control circuit the said signal may be applied to the cutting stylus to modulate the cutting depth thereof in such a manner as to produce image light redistribution microelements having a desired contour. Since the signal recorded on the memory element is used to control the cutting of each row, the microelements in each row maintain an identical phase relationship with the microelements in adjacent rows. Thus the present invention provides a simple and

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inexpensive means to produce projection screens exhibiting improved aesthetic appearance.

5 The invention will become more apparent from the ensuing detailed description of the preferred embodiment which follows by way of example, reference being made to the accompanying drawings in which:—

10 Figure 1 is a photograph taken through an interference microscope of a preferred embodiment of projection screen fabricated in accordance with the present invention;

15 Figure 2 is a perspective view of apparatus adapted to translate a blank projection screen or master relative to a cutting apparatus;

20 Figure 3 is a block diagram of the preferred circuitry for driving the cutting stylus of the cutting apparatus;

25 Figure 4 is a block diagram of a preferred circuitry for generating the desired randomized waveform which is recorded on the memory element;

Figure 5 is an electrical schematic diagram of the counter-balancing asymmetrical circuit illustrated in Figure 4.

30 The photograph of Figure 1 illustrates the positioning of microelements of a projection screen surface 11 fabricated in accordance with a preferred embodiment of the present invention. The rows of microelements extend across the photograph but the microelements randomly vary in scale or overall size (i.e., the width and amplitude of the microelements varies simultaneously so that their ratio, and therefore the light distributing properties of the microelements, remains the same) while maintaining an identical phase relationship with the microelements in adjacent rows.

35 Projection screens having a light-distributing surface similar in appearance to that illustrated by surface 11 may be fabricated by a stereo recording head, equipment conventionally employed in the sound recording industry, controlled as described below. Equipment of this type is shown in Figure 7 of Patent Specification 1,421,139, and may be used to form a screen per se or to fabricate a screen master from which projection screens may be pressed by well-known and economical duplicating process, such as embossing, stamping or injection moulding.

40 A sound recording head which has been found particularly well adapted for cutting projection screen masters is the Westrex Corporation, Model 3D Stereo Disc, as shown in Patent Specification No. 1,142,139.

45 As shown in Figure 12 of Patent Specifications 1,421,138 and 1,421,139,

because of the arcuate motion of the cutting stylus, the stylus must be driven with symmetrical waveform. Circuitry to provide the desired counterbalancing asymmetrical waveform is shown in the accompanying Figure 5. 70

In fabricating projection screen masters by use of the apparatus described above, the work piece is moved relative to the heated cutting stylus in a series of equally spaced, parallel traverses. At the same time, the cutting position of the stylus S is varied under electronic control relative to the surface of a blank master to produce the desired longitudinal cross section or depth profile. Apparatus for moving the master relative to the stylus is depicted in Figure 2. This apparatus is generally similar to that shown in Figure 11 of Patent Specification No. 1,421,138 with the addition of elements 13, 14, 16, 17 and 19. 75 80 85

Rigidly attached to the milling machine carriage 93 is a rigid member 13. Two projections 14 made of a magnetic material such as steel are mounted on the member 13. A magnetic sound recording tape 16 on which the desired stylus control waveform is recorded is stretched between the projections 14. The tape is held firmly onto the projections 14 with permanent magnets 17. A sound pickup head 19 is mounted onto the base of the cutting apparatus and therefore fixed in space relative to the table 80. Such head is pushed lightly against the tape 16. The signal generated by the pickup head 19 is processed by control circuitry shown in Figure 3 and then applied to the cutting stylus. 90 95 100

Preferred circuitry for producing the waveform recorded on the magnetic tape 16, and generated by the pickup head 19 is shown in Figure 4. The circuit includes a frequency modulatable sine wave generator 200, a zero crossing or zero value detector 202 that provides an output signal each time the sine wave passes through zero, one-shot generator 204 that produces one narrow width pulse in response to each zero-crossing signal, a sample and hold module 206 that acquires a voltage from a signal source 208 during the width of the output pulse produced by the one-shot generator 204 and then stores this voltage essentially unchanged until the next sample command pulse arrives from this generator, a circuit 210 which generates an asymmetrical waveform to counterbalance the asymmetry produced by the arcuate travel path of the cutting stylus, a shape circuit 212 which converts the frequency modulated sine wave output of the generator 200 into a waveform having the desired microelement contour and an analog divider module 214 wherein the shaped waveform is divided by a voltage 105 110 115 120 125 130

proportional to its frequency so that the "optical power" of the microelements remains constant. "Optical power" as used herein refers to the ability of a microelement to redistribute image flux throughout a predefined solid audience angle.

The basic sinusoidal waveform from which the stylus cutting signal is ultimately derived is produced by the sine wave generator 200. In order to randomly vary the size of adjacent microelements, the zero-crossing detector 202 provides an output signal each time the sine wave produced by the generator 200 passes through zero. Each output signal of the detector 202 activates a one-shot generator 204 to produce a pulse whose width is an insignificant fraction of the period of the sine wave, for example less than one percent. Upon receipt of the pulse from the one-shot generator 204, sample and hold module 206 requires a modulating voltage provided by the signal source 208 that is completely incoherent relative to the sine wave produced by the generator 200. As a result of this relative incoherency, the values assumed by the modulating voltage in successive sampling periods is strictly a matter of statistics, related only to the waveform produced by the source 208. For example, if the waveform of source 208 is of triangular shape and of much higher frequency than any frequency of the sine wave produced by the generator 200, the probability distribution of the successive values of the modulating voltage is flat between two sharp limits. The modulating voltage acquired by the module 206 from the source 208 during the period of the pulse from the one-shot generator 204 is applied to the generator 200 as a frequency modulation until the waveform produced by generator 200 passes through zero, at which time a pulse from the detector 202 causes generator 204 to command the module 206 to again sample the amplitude of the voltage from the source 208 and apply this voltage to the generator 200 as a frequency modulation. It can be seen therefore that the frequency of the waveform changes abruptly each time a command signal is received by the sample and hold module 206.

To cut microelements having a cross-section which is contoured to redistribute normally incident radiation in such a manner as to produce a uniform radiance throughout a solid angle, a waveform must be generated that differs from a true sine wave in that the peaks are flattened relative to the lower amplitude portions of the wave. The determination of the equations defining such a waveform form no part of the present invention. These equations are

disclosed in Patent Specification No. 1,421,138. To produce the desired waveform from the frequency modulated sine wave output of the generator 200, such output is fed to the shape circuit. The output of shape circuit 212 is then fed to the Z input of the analog divider module 214 through a capacitor C1 which eliminates any drift or offset in shape circuit 212. The detailed structure and operation of this circuit is not part of the present invention. It is equivalent to circuit 211 in Figure 20 of both Patent Specifications Nos. 1,142,138 and 1,421,139.

As indicated above, in order to drive the cutting stylus in such a manner as to cut symmetrical microelements along the groove length, it is necessary to apply an asymmetrically distorted waveform to the drive coils of the stylus which, due to the arcuate movement of the stylus, is converted into the desired groove-cutting stylus movement. It has been determined that the required asymmetry can be achieved if the frequency modulated output of the sine wave generator 200 is divided by a term that includes the cosine of the same frequency. Thus:

$$(1) \quad Y' = \frac{Y}{A(1 \pm k \cos wt)}$$

where

Y is the sine wave output (a sin wt) of the generator 200

Y' is the desired asymmetrically distorted waveform

A is an arbitrary scale constant

k is an adjustable distortion parameter

w is the angular frequency in radians per second, and

t is time in seconds.

As shown in Figure 5, the portion of the circuit 210 comprising resistors R1 and R3, capacitor C2 and operational amplifier A1 determines the differential of the sine wave output of the generator 200 according to the equation:

$$(2) \quad d/dT \cdot Y = d/dT \cdot (a \sin wt) = aw \cos wt$$

where

a is the amplitude of the waveform, and w is the angular frequency in radians per second.

The equation shows that the differential of the sine wave output is the cosine wave with an amplitude that is proportional to frequency. Since the divisor of Equation 1 needed to adjust the amplitude Y' so as to keep the waveforms similar is also a constant (over one full cycle at least) that is proportional to frequency, the differential voltage is added directly to a voltage

proportional to frequency ($V\Omega$) available from an auxiliary output of the generator 200. The potentiometer P1, resistor R5 and amplifier A2 provide adjustable gain control and thus determine the value of the parameter k which is arbitrary and independent of frequency. Resistors R2, R4 and R6 provide proper impedance matching for the various circuit components. The output of circuit 210 which is the divisor shown in equation (1) above, is fed to the Y input terminal of analog divider module 214. The analog divider module 214 divides the instantaneous amplitudes of the input signal Y and Z so as to provide an output, the amplitude of which is inversely proportional to frequency. Since the frequency applied to terminal Z increases as the amplitude of the signal applied to terminal Y increases, the amplitude to frequency ratio remains constant. As a result there is no discontinuity in slope for adjacent microelements, only an abrupt change in scale.

As switch 216 (see Figure 4) coupled between the zero-crossing detector 202 and the one-shot generator 204 allows the scale change to be made after one complete cycle of the waveform or alternatively, after every half cycle of the waveform. If the switch 216 is open so that the zero crossing detector 202 is connected to only the one input of the one-shot generator 204 the size of the cut microelement remains constant for one full cycle as shown in Figure 2. If the switch 216 is closed so that the detector 202 is connected to both the direct and inverted inputs of the one-shot generator 204, the size of the cut microelement changes every half cycle.

Although it is preferred that the output of analog divider module 214 (Figure 4) be used to record the signal on magnetic sound recording tape 16, which in turn is used in the apparatus shown in Figure 3, the invention also contemplates the use of the output of this module 214 to drive the cutting stylus directly. This arrangement would eliminate colour banding but would not minimize streaking. It is preferred however that the streaking be eliminated by properly phasing the microelements in adjacent rows, as described below.

In Figure 3, the preferred control circuitry for driving the cutting stylus in such a manner as to produce microelements which distribute image throughout a common solid audience angle is illustrated in block form. The waveform of the electrical signal applied to the coil which drives the stylus, of course, determines the depth profile of each of the rows of microelements. As shown, the

signal recorded on the tape 16 and detected in the pickup head 19 is passed through an amplifier 100 and a band pass filter 106 which is designed to pass only the fundamental waveform recorded on the magnetic tape 16. The output of the band pass filter 106, which is essentially noise free, is then applied to the drive coils of the cutting stylus to produce the desired profile. Since the magnetic sound recording tape 16 tracks with the carriage 93, the sound pickup head 19 applies the same portion of the waveform recorded thereon the drive coils of the cutting stylus during the cutting of each row. As a result, the microelements in each row maintain an identical phase relationship with the microelements in adjacent rows.

After making a positive master for a projection screen in accordance with the afore-described method, projection screens can be produced therefrom by making a negative matrix from the positive master, and casting projection screens in a resinous material directly from the negative matrix, for example as disclosed in Patent Specifications 1,421,138 and 1,421,139.

The invention has been described in detail with reference to a preferred embodiment thereof, but it will be understood that modifications can be effected within the scope of the appended claims. For example, other magnetic, electrical, optical or mechanical memory elements can be substituted for the magnetic tape 16 provided, of course, that an appropriate pickup head is also selected to transform the recorded waveform into a series of electrical pulses.

WHAT WE CLAIM IS:—

1. A projection screen of the type having a surface defining a plurality of contiguous grooves, each of the grooves having a depth which undulates along the groove length in accordance with a periodic waveform and thereby defines a row of alternately concave and convex optical microelements which are contoured to redistribute incident radiation uniformly throughout a predefined solid audience angle, wherein both the length and amplitude of the microelements in each row changes at the points corresponding approximately to the completion of each cycle of the said waveform and the amplitude to length ratio of the microelements remains constant, the said length and amplitude changes providing periodic, abrupt changes in the scale of the microelements which vary by a random amount while maintaining substantially identical the absolute value of the slopes of corresponding point on the contours of the microelements.



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proportional to frequency ($V\Omega f$) available from an auxiliary output of the generator 200. The potentiometer P1, resistor R5 and amplifier A2 provide adjustable gain control and thus determine the value of the parameter k which is arbitrary and independent of frequency. Resistors R2, R4 and R6 provide proper impedance matching for the various circuit components. The output of circuit 210 which is the divisor shown in equation (1) above, is fed to the Y input terminal of analog divider module 214. The analog divider module 214 divides the instantaneous amplitudes of the input signal Y and Z so as to provide an output, the amplitude of which is inversely proportional to frequency. Since the frequency applied to terminal Z increases as the amplitude of the signal applied to terminal Y increases, the amplitude to frequency ratio remains constant. As a result there is no discontinuity in slope for adjacent microelements, only an abrupt change in scale.

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The invention has been described in detail with reference to a preferred embodiment thereof, but it will be understood that modifications can be effected within the scope of the appended claims. For example, other magnetic, electrical, optical or mechanical memory elements can be substituted for the magnetic tape 16 provided, of course, that an appropriate pickup head is also selected to transform the recorded waveform into a series of electrical pulses.

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2. A projection screen as claimed in Claim 1 wherein the said length and amplitude changes occur at points corresponding approximately to the completion of each half-cycle of the said waveform.

3. A projection screen as claimed in Claim 1 or Claim 2, wherein the microelements in each row have an identical phase relationship with the microelements in adjacent rows.

4. A negative matrix formed so that projection screens in accordance with any one of Claims 1, 2 and 3 may be cast directly therefrom.

5. A positive master from which a negative matrix as claimed in Claim 4 may be made in preparation for casting a projection screen directly from the negative matrix.

6. A method of making a projection screen as claimed in any one of Claims 1, 2 and 3, substantially as hereinbefore described with reference to the accompanying drawings.

7. A projection screen made by the method of Claim 6.

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