United States Patent [19]

Hoadley et al.

[11] **3,788,171**

[45] **Jan. 29, 1974**

[54] **PROJECTION SCREEN FABRICATION APPARATUS AND METHOD**

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[73] Assignee: **Eastman Kodak Company,** Rochester, N.Y.

[22] Filed: **Dec. 13, 1971**

[21] Appl. No.: **207,383**

[52] **U.S. Cl.** ..... **83/5,** 83/701, 90/13 C

[51] **Int. Cl.** **B26d 3/06**

[58] **Field of Search** ..... 83/5, 701; 51/59 SS, 59 R; 82/DIG. 9; 90/13 C

[56] **References Cited**

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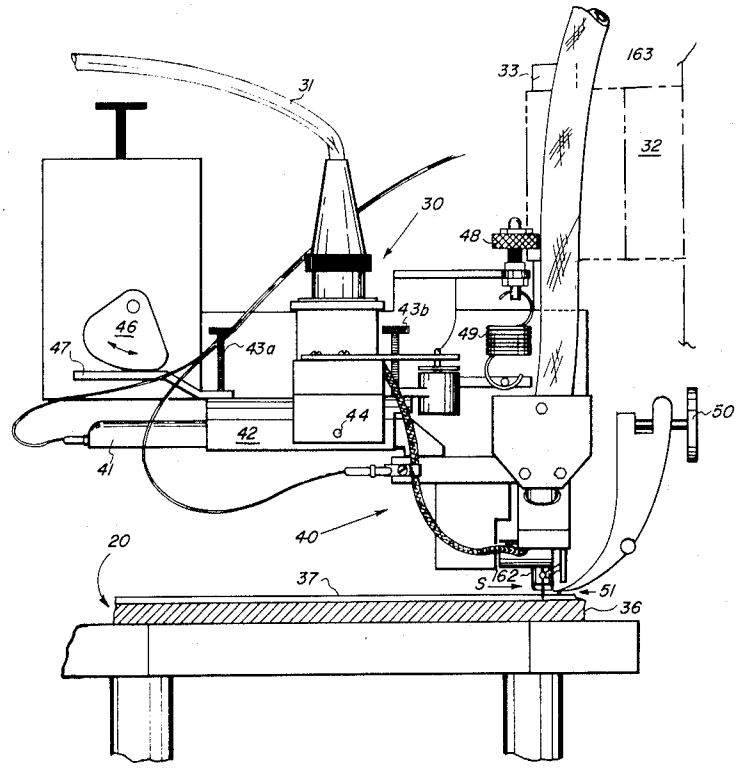
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Primary Examiner—J. M. Meister

[57] **ABSTRACT**

A method and apparatus for fabricating projection screen masters from which highly efficient projection screens of improved aesthetic quality can be replicated. The cutting stylus of a sound-recording head is used to cut a plurality of contiguous grooves in the surface of a blank master. A signal of predefined waveform but of random frequency is applied to to the cutting stylus to modulate the cutting depth thereof in such a manner as to produce image light-redistribution microelements of various sizes but of substantially identical optical power.

7 Claims, 10 Drawing Figures



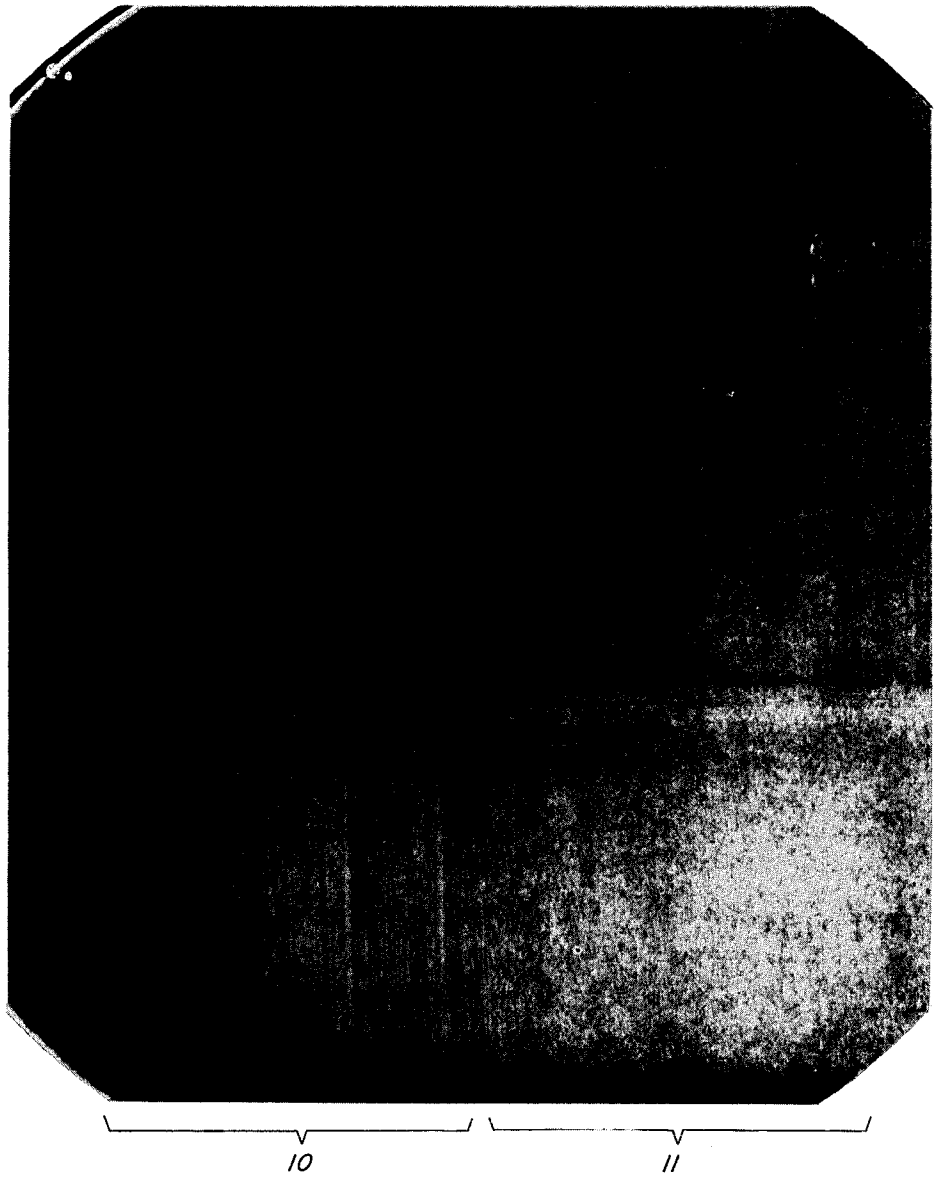
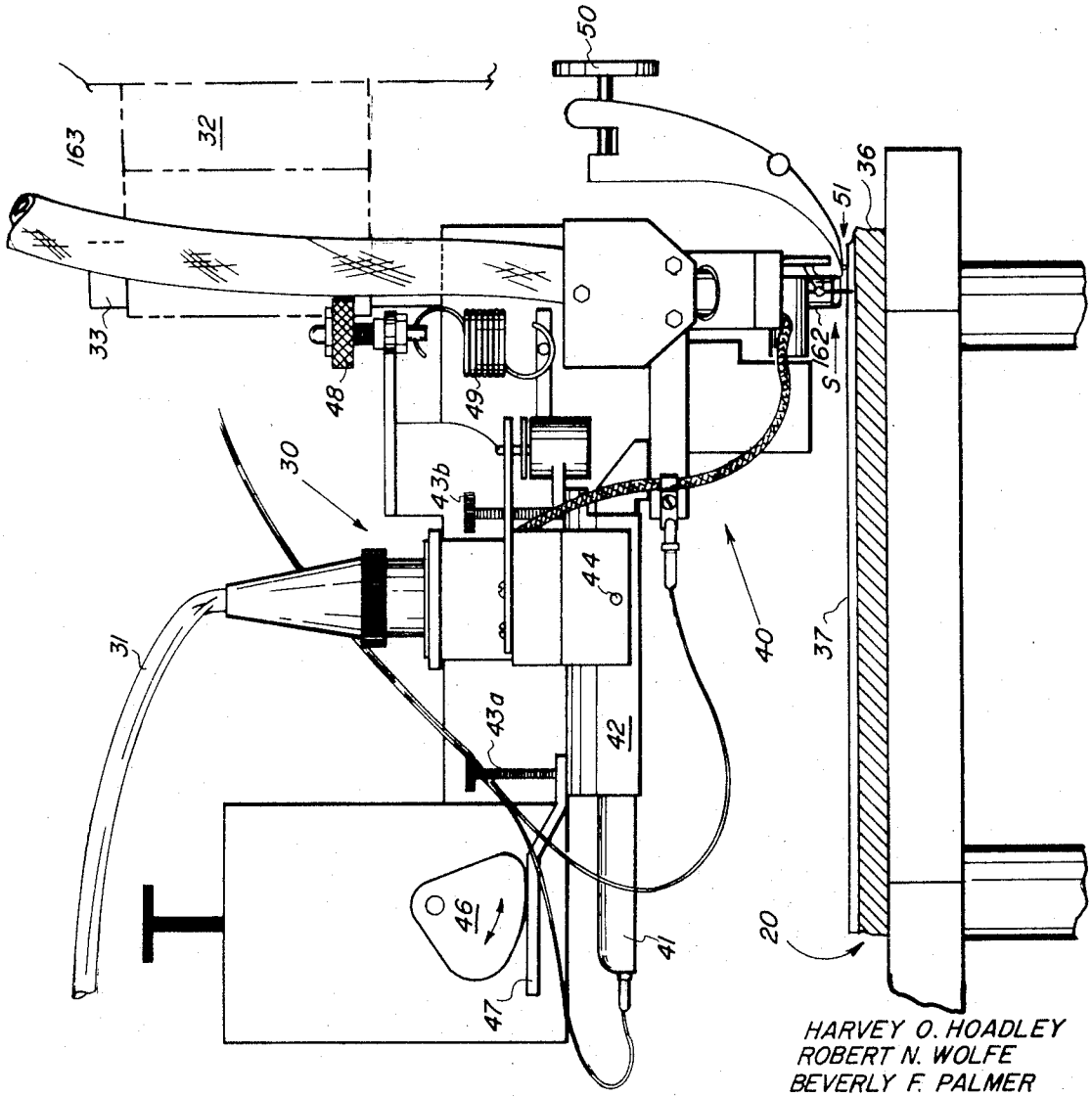


FIG. 1

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FIG. 2



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FIG. 3

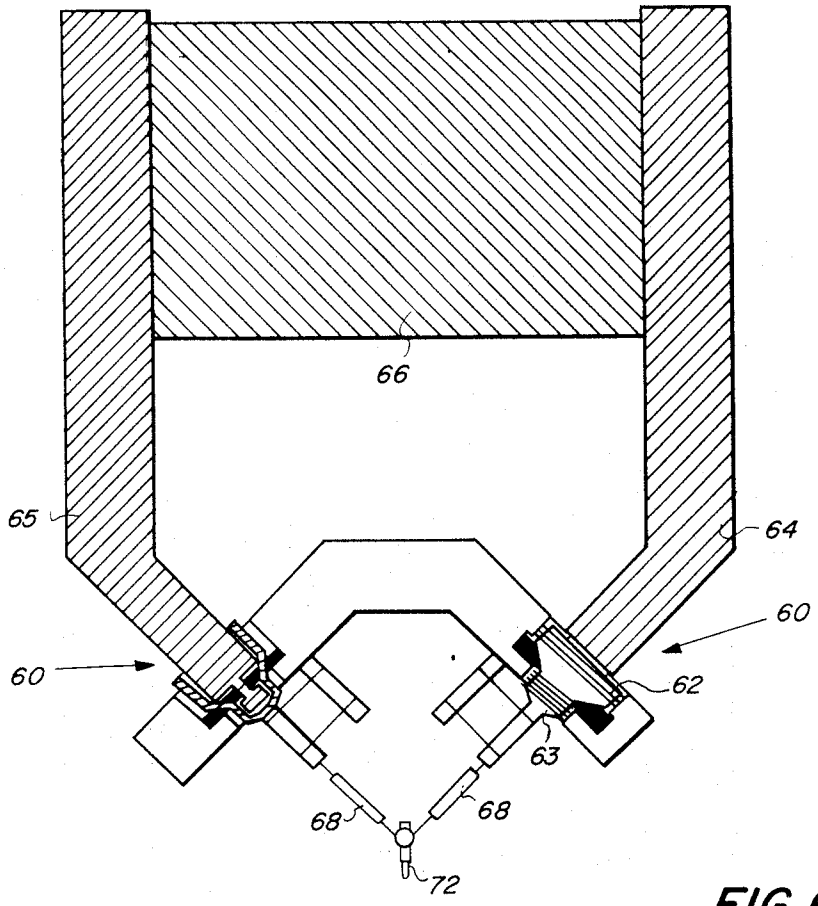
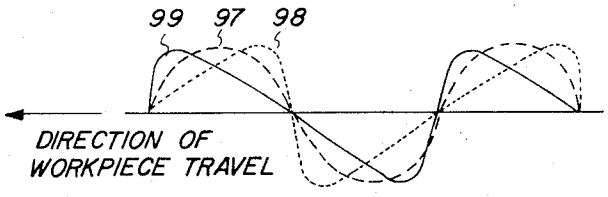


FIG. 6



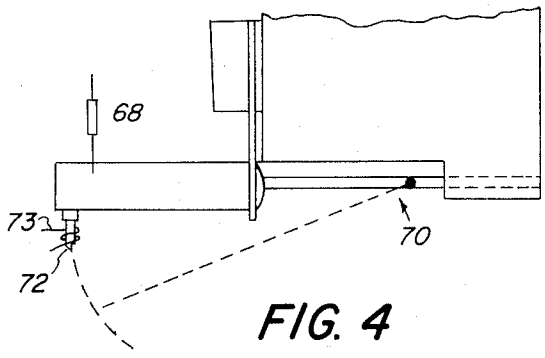


FIG. 4

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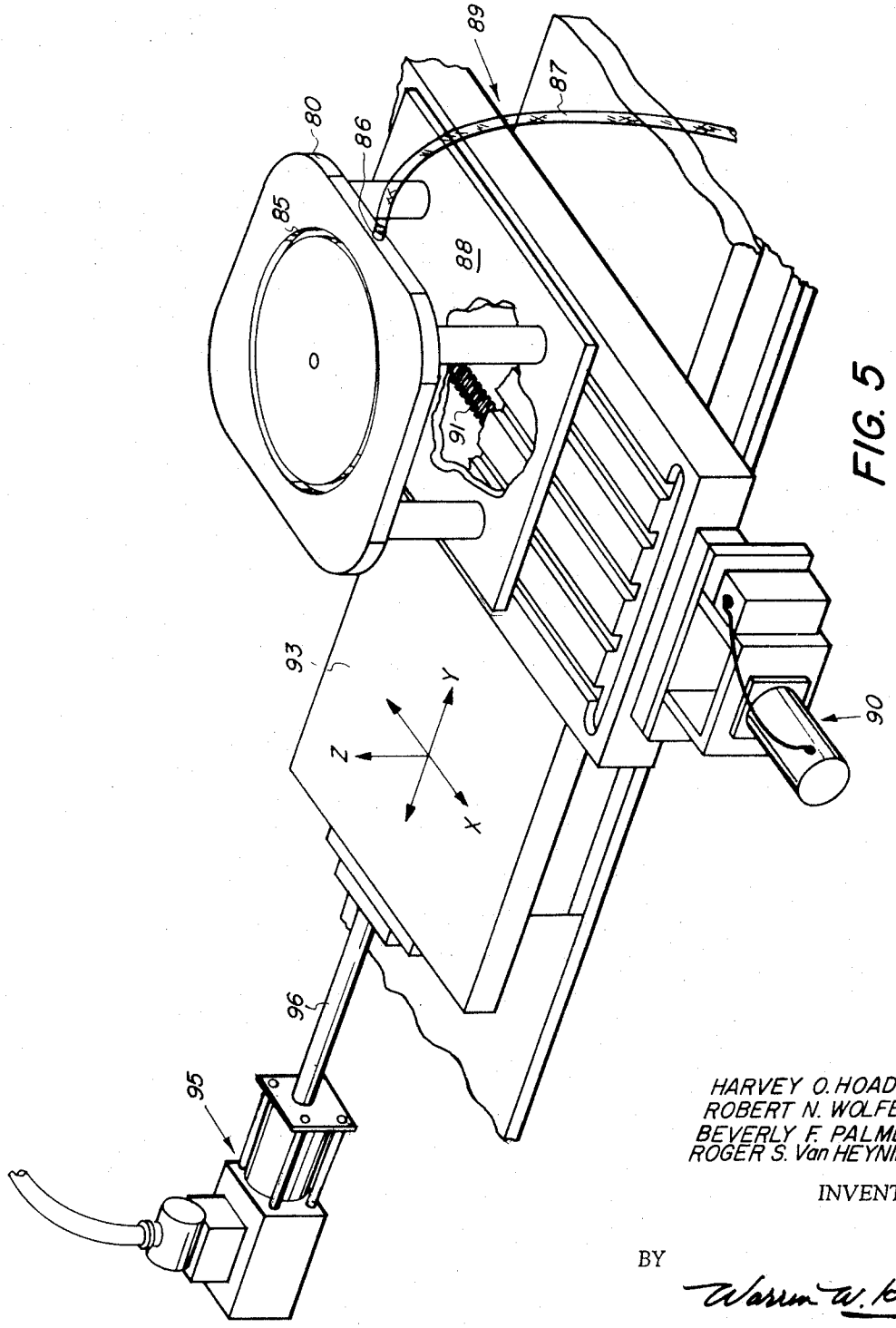


FIG. 5

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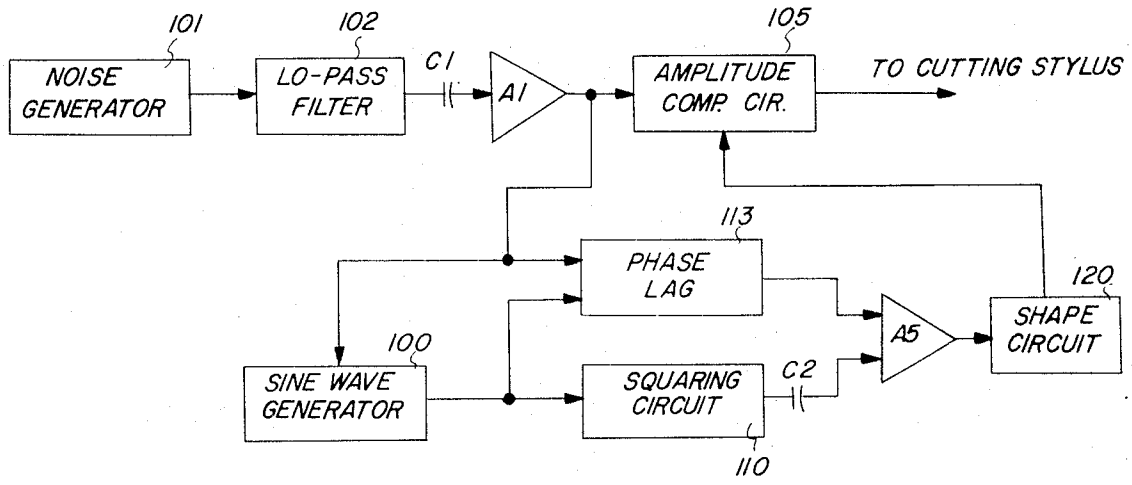


FIG. 7

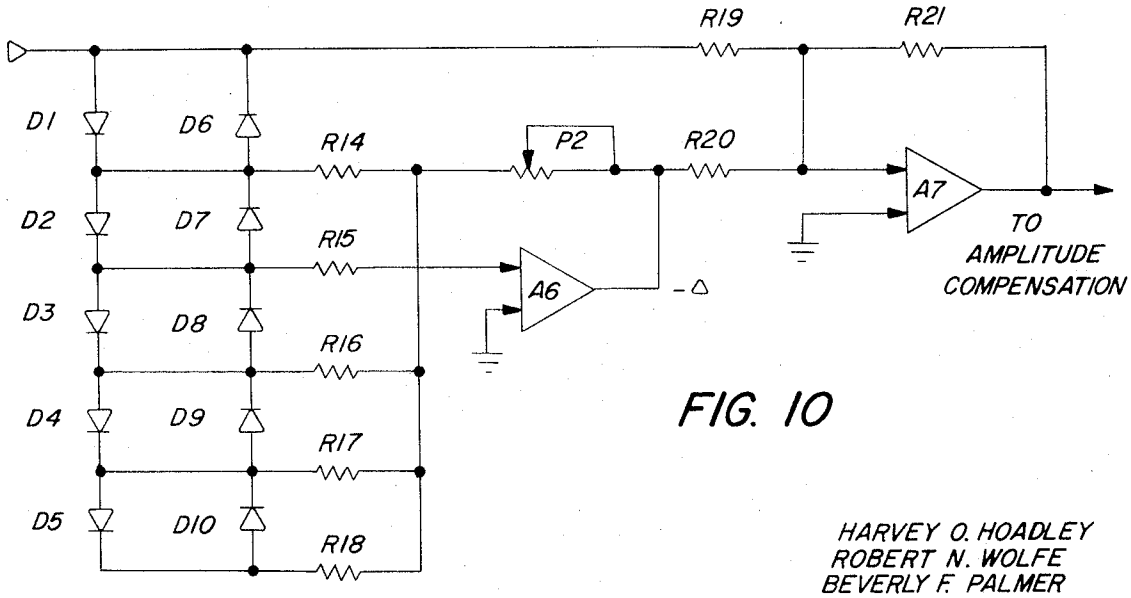


FIG. 10

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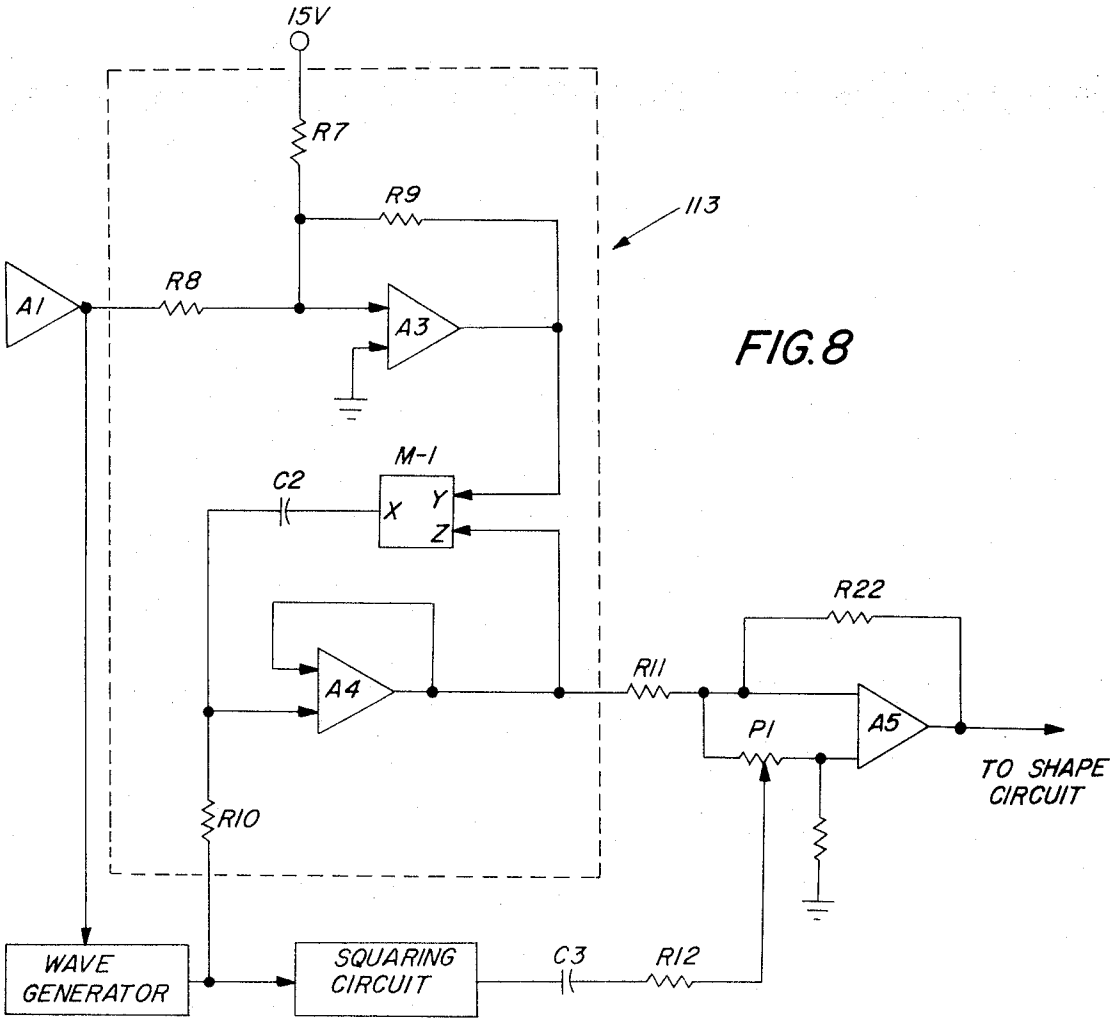


FIG. 8

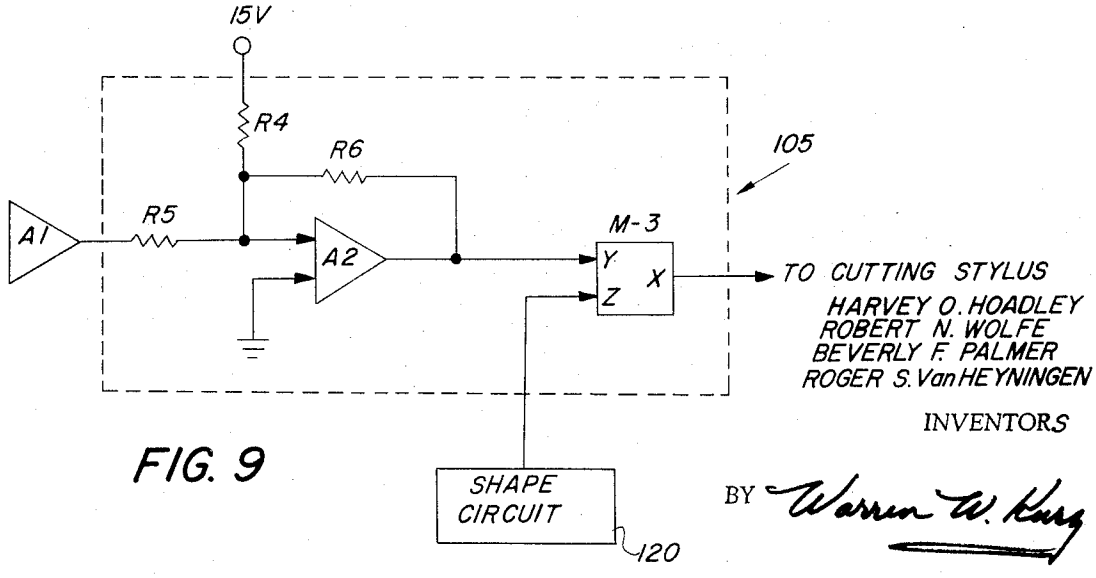


FIG. 9

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PROJECTION SCREEN FABRICATION APPARATUS AND METHOD

CROSS REFERENCE TO RELATED APPLICATIONS

Reference is made to the commonly assigned copending applications, Ser. No. 207,082, filed concurrently herewith in the names of J. J. DePalma et al, entitled "Radiation-Redistributive Devices;" and Ser. No. 207,084, filed concurrently herewith in the names of H. O. Hoadley et al, entitled "Projection Screen."

BACKGROUND OF THE INVENTION

The present invention relates to the fabrication of front and rear projection screens of the type comprising a multitude of contiguous optical microelements, each being specially contoured to distribute image flux in such a manner that its luminance will be substantially constant wherever viewed within a predefined common solid audience angle. More particularly, the present invention relates to the fabrication of screen masters from which aesthetically pleasing screen surfaces of high efficiency can be replicated.

In the commonly assigned copending application Ser. No. 207,082, filed concurrently herewith in the names of J. J. DePalma et al, there is disclosed a projection screen having an image-light-distributing surface which comprises a plurality of contiguous grooves. The depth of each of such grooves undulates in a periodic manner material the groove length in accordance with a predetermined waveform to define a row of optical microelements which, in a preferred embodiment, alternate from concave to convex in shape. Each microelement is substantially identical in size, whether concave or convex, each having a contour such as to redistribute incident image requisite such that its luminance is substantially constant everywhere within predefined horizontal and vertical audience angles. Also disclosed in the same application is a method for fabricating such a screen surface. Briefly, the method comprises cutting the grooves in the surface of a blank master with the stylus of a sound-recording head, while electronically modulating the cutting position of the stylus with an electrical signal of such waveform as to produce the groove depth profile desired when applied to the recording head.

While the projection screen described in the above application performs quite satisfactorily in distributing image light, it has been found that the appearance of such a screen is not, when illuminated with image light or room lighting, aesthetically pleasing when manufactured in accordance with the method disclosed. Ideally, the depth profile of each groove should be perfectly in phase with that of all other grooves. However, since the grooves are necessarily cut in a sequential manner, the workpiece from which the projection screen is eventually fabricated being moved past the cutting stylus in a series of equally spaced parallel traverses, it is exceptionally difficult, due to minute variations in the velocity of the work table and in the frequency of the signal used to modulate the depth of cut of the cutting stylus to maintain the ideal phase relationship from one groove to another. Commonly, the screen surface exhibits random streaks of light and dark areas running parallel to the grooves which are unpleasing 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 color where there should be none.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method and apparatus for fabricating highly efficient and directional projection screens of improved aesthetic qualities.

Another object of the invention is to improve the aesthetic appearance of projection screen surfaces of the type which comprise a multitude of specially contoured optical microelements by providing a method and apparatus for randomly varying the size of the microelements over the screen surface in such a manner as to give the surface a velvet-like appearance when viewed under normal room light or projected image light.

Another object of the invention is to improve the uniformity of the luminance and color, when viewed from any point within a predefined solid audience angle, of projection screen surfaces of the type comprising a multitude of optical microelements, by providing a method and apparatus for randomly varying the size of the microelements over the screen surface in such a manner as to prevent the formation of regular diffraction fringes in the light redistributed by such surface.

In accordance with the present invention, the above objects are achieved by employing the cutting stylus of a sound-recording head as a tool for cutting the screen surface and by modulating the cutting position of the stylus in such a manner that, as contiguous grooves are cut in the surface of a blank master, the depth of each groove is caused to undulate at a random spatial frequency and thereby define alternately convex and concave optical microelements of random length but of substantially identical contour and optical power. Circuitry is provided for frequency-modulating a predefined stylus-driving signal with low-frequency noise, and for varying the depth of cut in accordance with the instantaneous frequency of the stylus-driving signal.

Other objects of the invention and its various advantages will become immediately apparent to those skilled in the art from the ensuing detailed description of preferred embodiments, reference being made to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a photograph comparing a projection screen surface fabricated in accordance with the present invention with a screen surface fabricated in accordance with the method and apparatus disclosed in the aforereferenced application;

FIG. 2 is a side elevational view illustrating a portion of a sound-recording head used to fabricate screen masters in accordance with the present invention;

FIG. 3 is a constructional front elevational view of a portion of a stero sound-recording head;

FIG. 4 is a side view of the cutting stylus of the recording head of FIG. 3, illustrating the stylus support;

FIG. 5 is a perspective view of apparatus adapted to translate a blank projection screen master relative to the screen-cutting apparatus depicted in FIG. 2;

FIG. 6 illustrates the manner in which the waveform of the stylus-driving signal differs from the stylus motion produced thereby;

FIG. 7 is a block diagram of preferred circuitry for driving the cutting stylus of a sound-recording head to produce a projection screen master in accordance with the invention;

FIG. 8 is an electrical schematic of the phase-lagging circuit of FIG. 7;

FIG. 9 is an electrical schematic of the amplitude compensation circuit of FIG. 7; and

FIG. 10 is an electrical schematic of the shaping circuit illustrated in FIG. 7.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The photograph of FIG. 1 compares the room-light appearance of a projection screen surface 10 fabricated in accordance with the method and apparatus disclosed in the above-referenced application of Hoadley et al, with a projection screen surface 11 fabricated in accordance with the present invention. Surface 10 defines a plurality of contiguous grooves of substantially uniform width which, as viewed in FIG. 1, run in a vertical direction. The depth of each groove undulates periodically along the groove length at a substantially constant spatial frequency, thereby defining a row of optical microelements of substantially equal half wave length, alternating from concave to convex in shape along the groove length. Each microelement, whether convex or concave, is contoured such as to redirect normally incident image flux in such a manner that its luminance is substantially constant throughout predefined horizontal and vertical audience angles. Because of the uniform groove width and constant wavelength of depth undulation, each microelement is substantially the same size as all other microelements. The physical dimensions of each microelement are such as to be unresolvable by the closest intended viewer. Typically, microelement width and length vary from 0.001 to 0.010 inch, and the peak-to-peak groove depth is approximately 0.003 inch.

As indicated in the above-referenced applications, the transverse and longitudinal cross sections of a convex microelement which is contoured to redistribute normally incident image flux in such a manner as to produce substantially constant luminance throughout a predefined audience space bounded by viewing angles A and B (measured from the normal in the plane of the cross section) and substantially zero luminance elsewhere, must be substantially defined by at least a segment of the curve

$$u = \pm f(w;n) = \pm\left(\sqrt{1-w}\ \left(\sqrt{w} - 2n \right) + \cos^{-1} \sqrt{w} \right) \quad (1)$$

where n is the refractive index of the microelement (n being -1 in the case where the microelement is reflective); u and w are the microelement coordinates, w being measured in a direction parallel to the path of incident radiation, and u being measured in the plane of the cross section, perpendicular to w; and w has a value within the following limits:

$\cos^2 A \leq w \leq 1$, when $f(w;n)$ is positive and the microelement is refractive, and when $f(w;n)$ is negative and the microelement is reflective; and

$\cos^2 B \leq w \leq 1$, when $f(w;n)$ is negative and the microelement is refractive, and when $f(w;n)$ is positive and the microelement is reflective.

Similarly, the transverse and longitudinal cross sections of a concave microelement must be substantially defined by at least a segment of the curve

$$u = \pm g(w;n) = \pm\left(\sqrt{1+w}\ \left(\sqrt{-w} - 2n \right) + \cos^{-1} \sqrt{-w} \right) \quad (2)$$

wherein w has a value within the following limits:

$-1 \leq w \leq -\cos^2 B$, when $g(w;n)$ is positive and the microelement is refractive, and when $g(w;n)$ is negative and the microelement is reflective; and

$-1 \leq w \leq -\cos^2 A$, when $g(w;n)$ is negative and the micro-element is refractive, and when $g(w;n)$ is positive and the microelement is reflective.

The depth profile of each of the grooves comprising surface 10 is substantially defined by equations (1) and (2) above, and the transverse cross section of each of the grooves is substantially defined by equation (2). While the spatial frequency of groove depth undulation is substantially constant over the screen surface, the phase of such undulation varies from groove to groove. And while such phase variation has been found to have substantially no adverse effect on screen performance, it has been found to give the screen surface a somewhat streaky appearance which is rather unpleasant aesthetically.

Projection screen surface 11, while having substantially the same light distributing qualities as surface 10, is much more pleasing aesthetically when viewed under normal lighting conditions, having a velvet-like appearance rather than the streaky appearance of surface 10. Screen surface 11, like surface 10, comprises a plurality of undulating contiguous grooves extending in a vertical direction, as viewed in FIG. 1. However, unlike surface 10, the depth of the grooves comprising surface 11 does not periodically vary with a substantially constant wavelength. Rather, the groove depth varies with a random wavelength, within a predefined range of wavelengths, to define optical microelements which vary in size accordingly. Preferably, the range of microelement size is within approximately ± 20 percent of a mean size. Moreover, unlike surface 10, the microelement depth (or height, depending on the sense of the microelement, concave or convex) is not uniform over screen surface 11. Rather, the microelement depth varies in proportion to its length, so that each microelement, regardless of size, not only has a contour substantially defined by equations (1) and/or (2) above, but also an optical power like all other microelements. "Optical power," as used herein, refers to the ability of a microelement to redistribute image flux throughout a predefined solid audience angle.

In accordance with the present invention, projection screens having a light-distributing surface similar in appearance to that illustrated by surface 11 are fabricated by employing various equipment and techniques conventionally employed in the sound-recording industry. In FIG. 2, a side elevation of the screen-cutting apparatus of the invention is shown in a cutting position relative to a blank master 20 wherein the screen microelements are to be formed. While the microelements can be cut directly in any readily workable material which itself can be used as the projection screen, the preferred method of manufacture comprises the fabrication of a screen master in some workable material, such as acetate or wax, from which a negative matrix or press tool of correct contour can be subsequently made. The negative matrix can then be used to produce

a multitude of positive projection screens by well-known and economical duplicating processes, such as embossing, stamping or injection molding.

As shown in FIG. **2**, the cutting apparatus comprises a conventional stereo sound recording head **30** which includes a cutting stylus S. While a monaural sound recording head could be used, a stereo head is preferred due to the high quality of auxiliary equipment available for conventional stereo heads. As in all sound recording heads, the cutting position of the stylus is determined by the waveform of an electrical signal applied to the recording head, such as through input cables **31**. The recording head is mounted on a milling machine tool holder **32** by a cylindrical fitting **33**. Means are provided for controlling the vertical position of fitting **33** in the tool holder **32** so as to provide a coarse, vertical adjustment of the recording head **30** above the surface of the blank master. The blank master may comprise, for instance, an aluminum plate **36** having an acetate coating **37**, the thickness of which is sufficient to receive the contours of the projection screen surface. Recording head **30** comprises a cutting assembly **40** having a horizontally extending support arm **41** which is slidably mounted on precision ways disposed in a saddle **42**. By this arrangement, the horizontal position of cutting assembly **40** can be varied. Set screws **43***a* and **43***b* serve to lock arm **41** in a desired horizontal position. Saddle **42** is pivotally mounted about pin **44** disposed on recording head **30** so that the cutting stylus S, which forms a part of cutting assembly **40**, can be pivoted into engagement with the master. The rotational movement of a cam **46** serves to raise and lower the stylus relative to the surface of the master by contacting an arm **47** which is rigidly coupled with saddle **42**. The cutting force applied to the stylus is controlled by screw **48** which serves to adjust the tension in spring **49**. The precise depth of cut is controlled by adjustment screw **50** which varies the vertical distance of the stylus tip from a small glass ball follower **51** which rides on the uncut surface of the master a short, horizontal distance away from the stylus.

A sound recording head which has been found particularly well adapted for cutting projection screen masters is the Westrex Corporation, Model 3D StereoDisc. As illustrated in FIG. **3** wherein a simplified constructional diagram of the mechanism which controls stylus movement is shown, each recording channel of the stereo recording head contains a magnetic coil form assembly **60**, each of which contains a driving coil **62** located in separate pole pieces **64** and **65** which are attached to a single magnet **66**.

The coil assemblies are attached to the stylus holder through links **68** which are stiff longitudinally, but flexible laterally. These links are braced in the center to prevent excessive lateral compliance. This structure results in a stiff, forward driving system with a high compliance in the lateral direction.

The supporting member for the stylus is shown in FIG. **4**. The use of a cantilever spring **70** permits the stylus to present a uniform impedance to complex motions in any direction in the vertical plane. The cutting tip **72** of stylus S is preferably sapphire, but can be fabricated from any materail capable of cutting contours in the material used as the master. The cutting profile of the stylus is designed to conform with the desired transverse cross section of the screen elements, such as that defined by equation (1) above. To assist in cutting the workpiece with the requistie accuracy, the stylus is heated by heating coil **73** to a temperature such as to soften adequately the acetate coating of the screen blank.

in fabricating projection screen masters by use of the apparatus described above, the workpiece 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 is electronically varied relative to the surface of the blank master to produce the desired longitudinal cross section or depth profile. Apparatus for moving the master relative to the stylus is depicted in FIG. **5**. During the cutting operation, the master is supported by a table **80** which rides atop the cross travel carriage **81** of an *x–y* milling table **82**. Table **80** is preferably fabricated from a non-magnetic metal, such as aluminum, so as not to interfere with the magnetic cutting assembly **40**. In the upper surface of table **80**, a circular groove **85** is provided. At the base of groove **85** is an opening (not shown) which communicates with a nozzle **86** located on the edge of the table. Attached to nozzle **86** via hose **87** is a vacuum source (not shown). By this arrangement, the master is securely fastened to the surface of table **80** by a vacuum coupling. Carriage **81** is movable in the *x* direction and its position controlled with precision by a conventional stepping motor **90** which acts through lead screw **91** (not labeled). Carriage **81** itself rides atop the longitudinal travel carriage **93** of the *x–y* milling table **82**. Carriage **93** is movable in the *y* direction by a hydraulic pneumatic motor **95** which precisely controls the rate at which carriage **93** moves via piston rod **96**.

To move the cutting stylus in a vertical plane and at a rate which, when the screen blank is moved at a constant rate relative thereto, results in the longitudinal cross section or depth profile desired, the same signal must be applied, 180° out of phase, to both drive coils **62**. Moreover, since the stylus is not mounted for vertical movement, but rather for pivotal movement on the cantilever spring **70**, so as to traverse an arcuate path, as shown in phantom lines in FIG. **4**, it is necessary to drive the stylus with a somewhat different waveform than that which corresponds to the longitudinal cross section desired. Referring to FIG. **6**, when a waveform **97** is applied to the cutting stylus, the resulting groove has a depth profile as shown in the asymmetrical waveform **98**. To compensate for the asymmetry, it is necessary to drive the cutting stylus with a counterbalancing asymmetrical waveform **99** which the arcuate stylus movement converts to the depth profile desired (e.g., waveform **97**). It is interesting to note that in the sound recording art, such asymmetry is automatically compensated for during playback by the pickup stylus which is also pivotally mounted and, hence, moves along an arcuate path similar to that along which the stylus used to cut the original master recording moved. In achieving a desired profile for projection screens, however, such asymmetry must be compensated for by appropriate circuitry.

In FIG. **7**, preferred circuitry for driving the cutting stylus in such a manner as to randomly vary the size of the microelements cut thereby, without disturbing the ability of such elements to distribute image light uniformly throughout a common solid audience angle, is illustrated in block diagram form. Speaking in terms of a Fourier analysis, the signal applied to the driving coils of the cutting stylus to produce microelements having

a depth profile defined by equation (2) above is rich in harmonics. Therefore, if the signal is to pass with undistorted shape through the audio amplifier of the recording head, its fundamental frequency must lie near the lower end of the flat part of the pass-band of the amplifier, but not so low as to become subject to the phase distortion associated with the low-frequency cutoff characteristic. For this reason, the mean frequency of the wave generator **100** used to generate the basic sinusoidal waveform from which the stylus driving signal is ultimately derived was chosen to be 200 Hz, and it follows than that the length of the microelements is determined by the rate at which the screen blank is moved in *y*-direction past the cutting stylus. In order to randomly vary the size of each microelement by ± 20 percent of a mean size, the frequency of the signal applied to the cutting stylus must be randomly varied by ± 20 percent about 200 Hz, or from 160 to 240 Hz. To produce such random variation, the output of the wave generator **100** is frequency-modulated by a noise signal. Such a noise signal is provided by a conventional noise generator **101,** the output of which is fed through a low-pass filter **102** having a cutoff frequency of about 20 Hz. Capacitor C1 serves to eliminate any dc component in the noise signal. The amplitude of the noise generator **101** is set so that the frequency excursions of the cutting signal are contained almost entirely within the limits of ± 20 percent of the center frequency of 200 Hz. After passing through a buffer amplifier A1 the low frequency noise is applied to the wave generator. Generator **100** is of the type which provides an output frequency based upon the amplitude of an input voltage.

If the frequency of the cutting signal were altered while the amplitude thereof remained constant, the contour of each microelement would vary along the groove length, and each microelement would distribute image light over solid audience angles determined by its particular contour. In order to maintain the image flux-distributing power of each microelement constant, regardless of its size, it is necessary to change the amplitude of the cutting signal in concert with its frequency, in such a manner that the amplitude is always proportional to the wavelength of the cut, or inversely proportional to the cutting signal frequency. This implies that the cutting-signal amplitude must be under the control of the same modulating (noise) signal that frequency-modulates the output of generator **100.** Thus, the output of the noise generator is also applied to an amplitude compensation circuit **105,** described in detail hereinbelow.

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 driving coils of the cutting stylus which, due to the arcuate movement of the stylus, is converted into the desired groove-cutting stylus movement. It has been found that the required asymmetry can be substantially achieved by adding to the sinusoidal output of generator **100** a small amount of its second harmonic which is in phase with the fundamental frequency. A conventional squaring circuit **110** consisting of an analog multiplier module with the same signal applied to both inputs, is used to generate the second harmonic waveform (sin $2x$) from the fundamental. Capacitor C2 serves to eliminate the dc component of the output of circuit **110** which is $(\sin x)^2$. Since the midpoint of the resulting waveform lags the sin x waveform by 45°, it is necessary to feed the output of the wave generator through a phase-lagging circuit **113** before combining it with the second harmonic signal in summing operational amplifier A5. The output of the summing amplifier A5 is then fed through a shaping circuit **120** which converts the asymmetrical output of the summing amplifier A5 to the asymmetrical waveform required to drive the cutting stylus. The output of the shaping circuit **120** is then fed to the amplitude compensating circuit which acts to vary the amplitude of the shaping circuit output to a level inversely proportional to its instantaneous frequency. The output of the amplitude compensation circuit **105** is then applied to both input channels of the stereo sound-recording ampliifer.

When the output frequency of generator **100** is constant, the phase lag of 45° which is required of circuit **113** can be accomplished by a simple RC circuit. However, when the output of generator **100** is frequency modulated, such as by the noise generator **100,** the reactance of the capacitor varies with the instantaneous frequency, according to the formula $X_c = 1/2\pi fC$. This means that, as the frequency varies, both the phase lag and the amplitude of the output vary. To solve this problem, a constant reactance phase-lagging circuit was devised, such circuit being illustrated schematically in FIG. **8.**

As mentioned hereinbefore, the output frequency of wave generator **100** varies in accordance with the noise voltage v_n from amplifier A1. As shown in FIG. **8,** the output of the wave generator is applied to the phase-lag circuit which comprises resistor R10 and capacitor C2. Operational amplifier A4 is a high-input-impedance unity-gain isolation amplifier which ensures that the action of the phase-lag circuit is not altered by reason of being loaded by resistor R11 and the input impedance at terminal Z of module M-1. Module M-1 is an analog divider, which acts as an amplifier having a voltage gain, from Z to X, which can be varied under the control of an electrical signal applied to terminal Y.

Connected as shown in FIG. **8,** module M-1 causes the effective value of capacitor C2 to be larger than its actual value. Varying the gain of module M-1 results in a corresponding change in the effective value of the capacitance of C1. The gain-control signal for module M-1 is obtained by adding a constant voltage to the modulating noise voltage in operational amplifier A3. In the preferred embodiment, resistors R7, R8 and R9 are selected to make the output of amplifier A3 approxately $-(3 + 3.9\ v_n)$ volts, when the instantaneous frequency of the wave generator is $200(1 + v_n)$ Hz.

In accordance with the FIG. **8** circuit, the effective value of the capacitance is changed in concert with the output frequency of the wave generator in such a manner that the effective reactance X_c of capacitor C2 has a maximum change of only 1.6 percent while v_n varies over the range of ± 0.2 volts, and the output frequency of wave generator **100** varies between 160 and 240 Hz. An uncompensated capacitor would change its reactance over a total range of 41.7 percent of its median value for the same frequency changes. Thus, the effect of the constant reactance circuit of FIG. **8** is to hold both the phase shift and the amplitude of the output of amplifier A4 substantially constant while the wave generator frequency varies under the influence of the noise voltage. To vary the amount of second harmonic added

to or subtracted from the output of amplifier A4, a potentiometer P1 is connected as shown.

To produce the desired waveform from the asymmetrically distorted sine wave output of summing amplifier A5, output of the amplifier is fed to the shaping circuit 111. As shown in FIG. 10, this signal is segmented by reason of having to overcome successively the forward voltage drops across diodes D1–D10. Diodes D1–D5 and D6–D10 serve to segment the positive and negative-going portions of the input signal, respectively. Operational amplifier A6 serves to sum the contributions of the various segments to produce a difference signal Δx having a waveform representing the difference by which the desired waveform [equation (2) plus distortion] differs from the asymmetrically distorted sine wave. The contributions of the individual segments to the output of amplifier A6 are adjusted by varying the values of resistors R–14–R–18. The output of amplifier A6 is adjustable in amplitude by potentiometer P2. By simply adding the difference signal Δx, which is of a polarity opposite that of the unshaped signal due to the polarity reversing affect of amplifier A6, to the unshaped signal, the desired waveform for driving the cutting stylus is achieved. Such addition is performed by operational amplifier A7. Resistors R19 and R20 and potentiometer P3 serve to control the gain provided by the summing amplifier A7. The output of amplifier A7 is then fed to the input to the analog divider module M-3 of the amplitude compensation circuit.

in order for the cutting stylus to cut microelements of random size but of similar contour, it is necessary to vary the amplitude of the variable-frequency output of shaping circuit 120 so that the product of amplitude and frequency is substantially constant. As shown in FIG. 9, the output of shaping circuit 120 is fed to input terminal Z of an analog divider module M-3. Output X of module M-3 is proportional to Z/Y. The noise voltage v_n from buffer amplifier A1 is fed to operational amplifier A2 which adds a constant voltage to it, so that the output of amplifier A2 is proportional to $-(1 + v_n)$ and therefore also proportional to the instantaneous frequency of the wave generator. The output of A2 is then fed to input terminal Y of module M-3 which serves to divide the instantaneous amplitudes of the input signals so as to provide an output, the amplitude of which is inversely proportional to frequency. The frequency applied to terminal Z increases, as the amplituide of the signal applied to terminal Y increases.

Listed below are preferred values of the various circuit elements comprising the circuits illustrated in FIGS. 7–10.

R_1 — 10 K ohms	R_{15} — 47 K ohms
R_2 — 1 megohm	R_{16} — 68 K ohms
R_3 — 6.8 K ohms	R_{17} — 39 K ohms
R_4 — .15 megohms	R_{18} — 100 K ohms
R_5 — 10 K ohms	R_{19} — 5.6 K ohms
R_6 — 47.5 K ohms	R_{20} — 5.6 K ohms
R_7 — .475 megohms	R_{21} — 10 K ohms
R_8 — 24.4 K ohms	R_{22} — .10 megohms
R_9 — 94.8 K ohms	R_1 — 10 K ohms
R_{10} — 18 K ohms	P_2 — 10 K ohms
R_{11} — .10 megohms	C1 — 10 μ f.
R_{12} — .10 megohms	C2 — .01 μf
R_{13} — .10 megohms	C3 — 10 μf
R_{14} — 22 K ohms	

To initiate the cutting operation, a start button is pressed which pivots the recording head about pin 44 into a cutting position, causes pneumatic motor 95 to move carriage 93 in the y direction and causes the above-described electronic circuitry to drive the cutting stylus according to the waveform of the electrical signal applied thereto. After cutting a groove of predetermined length, a microswitch (not shown) is actuated by carriage 93 which serves to stop pneumatic motor 95, activate a solenoid which moves cam 46 of the recording head clockwise into a position to pivot the cutting assembly into an inoperative position, and actuate stepping motor 90 so as to move the carriage 81 a predetermined distance in the x direction. The microswitch also returns the carriage 93 to its starting position on the y-axis, which, in turn, actuates a second microswitch (not shown). When actuated, the second microswitch rotates cam 46 counterclockwise to permit the recording head to pivot into an operable cutting position, and the cutting process is repeated. This process continues without interruption until the entire screen master has been cut.

As the heated stylus S cuts a groove in the screen blank, a continuous sliver or chip is extricated from the screen blank surface. To continuously draw this sliver away from the screen blank, a vacuum nozzle 162 (shown in FIG. 2) connected to a vacuum source through hose 163, is positioned adjacent stylus S during the cutting operation.

After making the projection screen master in accordance with the afore-described method and apparatus, projection screens can be produced therefrom by making a negative matrix or master from the original, and casting positive screens, in a resinous material, from the negative matrix. Preferably, the negative matrix is made from General Electric RTV-60 silicone rubber which is prepared by adding 3 grams of dibutyl tin dilaurate RTV curing catalyst to 2 pounds of the RTV-60 rubber, agitating the mixture with an electric stirrer for 5 minutes and placing it in a bell jar which is then evacuated to a pressure of 150 microns of mercury for about 20 minutes. Upon fixing sidewalls to the edge of the original master, the RTV rubber mixture is poured into this mold. After curing, the rubber mold can then be used to cast positive projection screens.

The apparatus and methods set forth above are designed to produce planar projection screen surfaces comprising contiguous optical microelements which, while being of a random size within a predefined size range (determined by the amplitude of the noise voltage), are of substantially identical contour. Moreover, the orientation of each of the microelements is such that its optical axis is substantially parallel to the axes of all other microelements. By controlling the angle at which incoming image-light impinges on each microelement, such as by curving the redistributive surface (in the case of a front or reflection-type projection screen) or by using the surface in conjunction with a Fresnel-like lens (in the case of a rear or refraction-type projection screen) screen efficiency can be substantially enhanced. Since the solid angle through which each microelement redistributes image-light is a function of its angle of incidence on the micro-element surface, proper selection on the angle of incidence can be used as a means for directing the redistributed image-light from each microelement toward the audience space.

To fabricate such curved projection screens from masters having planar surfaces, the aforementioned rubber negative mold can be placed on the surface of a spherical or cylindrical section of desired radius of curvature prior to casting. A Maraglas epoxy resin, after being degassed, can then be poured into the mold.

After heating in an oven at 200° F for several hours to harden the resin, the casting can be coated with an aluminum coating to form a front projection screen.

This invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

We claim:

1. A method for fabricating a projection screen master having a surfaCe comprising means defining a plurality of parallel contiguous rectilinear grooves, each having a depth which undulates along the groove length, at a randomly changing spatial frequency within a predefined spatial frequency range, to define a row of contigous optical microelements of random sizes and of substantially uniform optical power, said method comprising the steps of:

cutting rectilinear grooves in the surfaces of a blank projection screen master with the stylus of a sound-recording head; and

simultaneously randomly modulating the cutting depth of the stylus in a plane perpendicular to said surface by applying an electrical signal to the recording head of random frequency and of an amplitude inversely proportional to the instantaneous frequency of said signal.

2. Apparatus for fabricating projection screens having an image flux-redistributing surface comprising means defining a plurality of rectilinear grooves, each groove having a depth which undulates along the groove length in such a manner as to define a row of alternately concave and convex optical microelements of random sizes, within a predefined size range, and of substantially uniform optical power, said apparatus comprising:

groove cutting means-including at least one cutting stylus and control means operatively coupled to said stylus and responsive to an electrical signal for controlling the cutting position of said stylus;

means for moving a blank projection screen master and said stylus relative to each other to cut a plurality of rectilinear grooves in at least one surface of said master; and

circuit means operatively coupled to said control means for generating an electrical signal for controlling the cutting position of said stylus during movement of said master surface and said stylus relative to eaCh other, said signal having a randomly varying frequency, within a predefined frequency range, and an amplitude inversely proportional to the instantaneous frequency thereof, whereby each of the grooves cut by said stylus has a depth which undulates along the groove length in such a manner as to define said row of alternately concave and convex optical microelements of random sizes within a predefined size range, and of substantially uniform optical power.

3. Apparatus according claim **2** wherein said moving means comprises means for moving said screen master relative to said stylus at a substantially constant velocity.

4. Apparatus according to claim **2** wherein said groove-cutting means comprises a sound-recording head.

5. Apparatus according to claim **2** wherein said circuit means comprises a voltage-controlled sine-wave generator, and noise means operatively coupled to said sine-wave generator for randomly varying the frequency of the sinusoidal output thereof.

6. Apparatus according to claim **5** wherein said circuit means further comprises means for asymmetrically distorting the sinusoidal output of said sine-wave generator.

7. Apparatus according to claim **6** wherein said crircuit means further comprises means operatively coupled to said distorting means and said noise means for varying the amplitude of the asymmetrically distorted output of said distorting means in a manner inversely proportional to the instantaneous frequency of said distorting means output.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,788,171 Dated January 29, 1974

Inventor(s) Harvey O. Hoadley; Robert N. Wolfe; Beverly F. Palmer, Roger S. Vanheyninge

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 30, "material" should read --along--;

Column 1, line 36, "requisite" should read --flux--;

Column 6, line 5, "in" should read --In--;

Column 9, line 59, "R_1 - 10 K ohms" should read --P_1 - 10 K ohms--;

Column 11, claim 1, line 11, "surfaCe" should read --surface--;

Column 11, claim 2, line 37, "means-including" should read --means including--;

Column 12, line 8, "eaCh" should read --each--;

Column 12, line 18, please insert the word -- to-- after the word according;

Column 12, line 34, "crir-" should read --cir- --.

Signed and sealed this 11th day of June 1974.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents

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