Sept. 16, 1969 G. A. MASSEY 3,467,216

APPARATUS AND METHOD FOR PRODUCING HOLOGRAMS WITH ACOUSTIC WAVES

Filed June 30, 1967 5 Sheets-Sheet 1

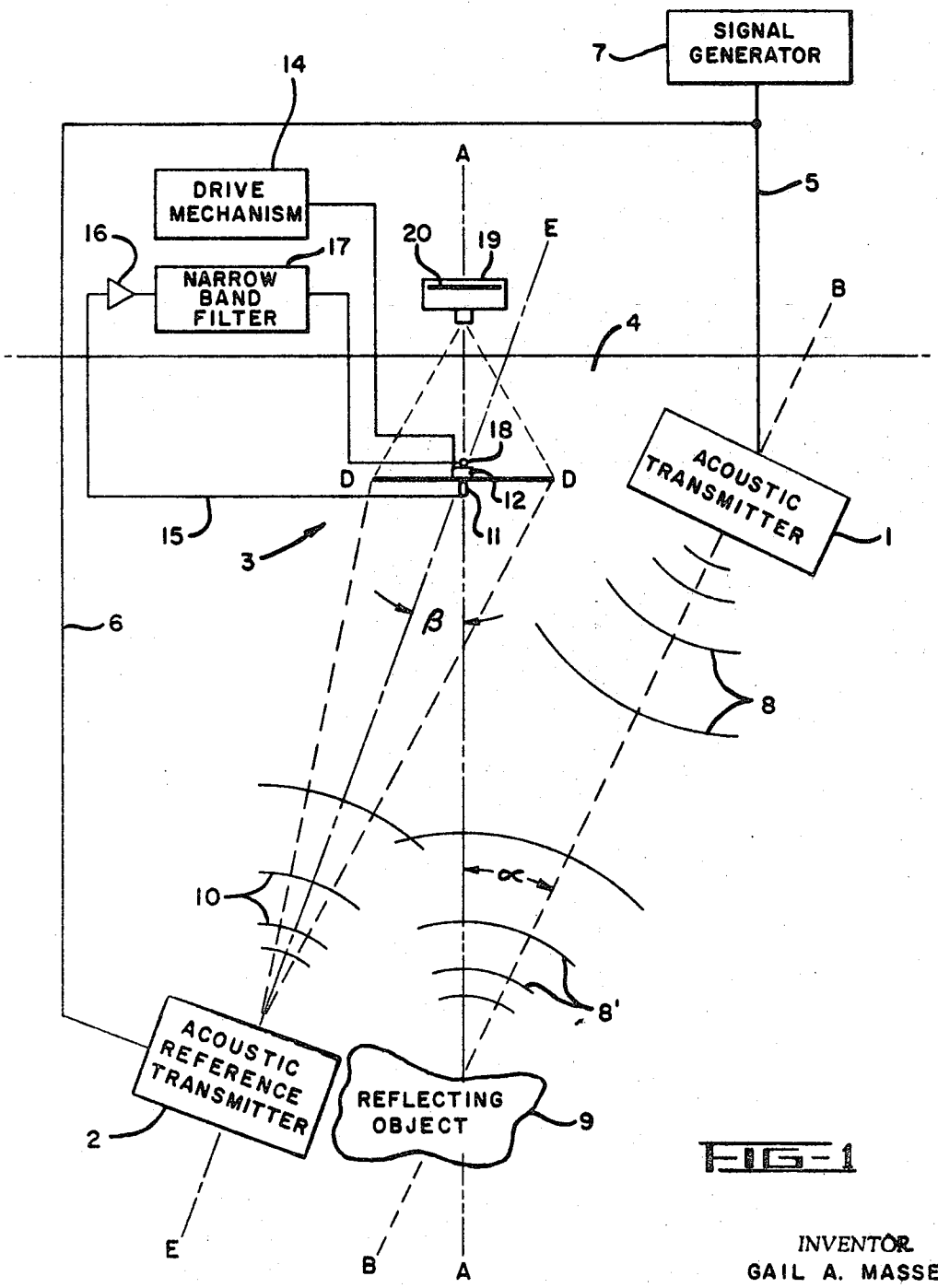


FIG-1

INVENTOR.
GAIL A. MASSEY

BY John F Lawler
ATTORNEY

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APPARATUS AND METHOD FOR PRODUCING HOLOGRAMS WITH ACOUSTIC WAVES
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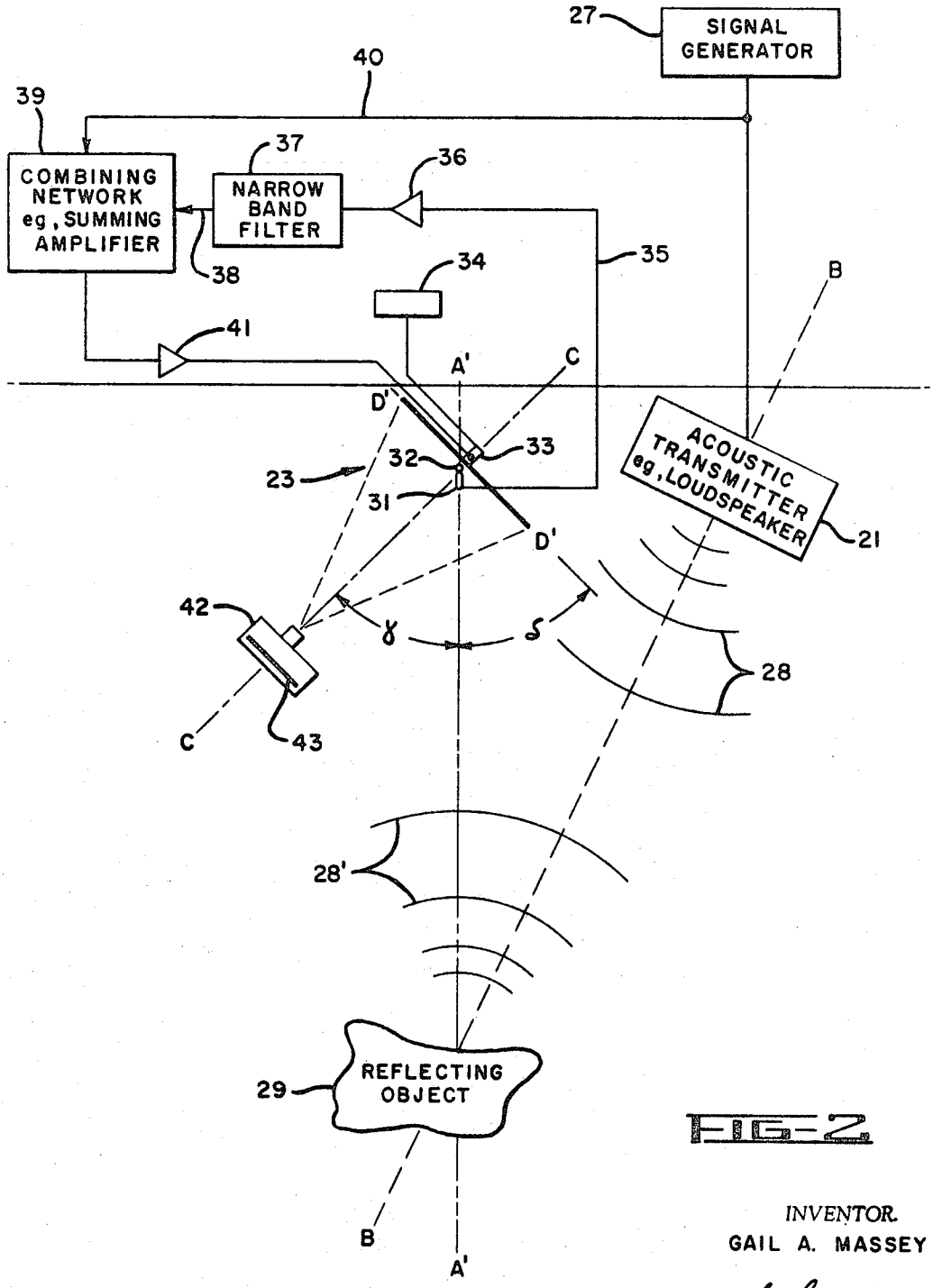


FIG-2.

INVENTOR.
GAIL A. MASSEY
BY J. Jan F. Lawler
ATTORNEY

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APPARATUS AND METHOD FOR PRODUCING HOLOGRAMS WITH ACOUSTIC WAVES
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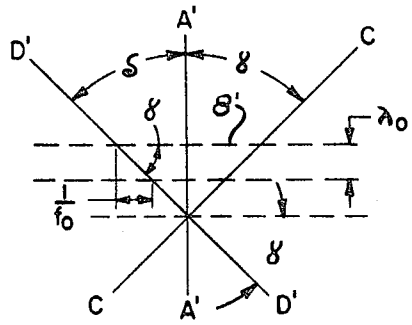


FIG-3

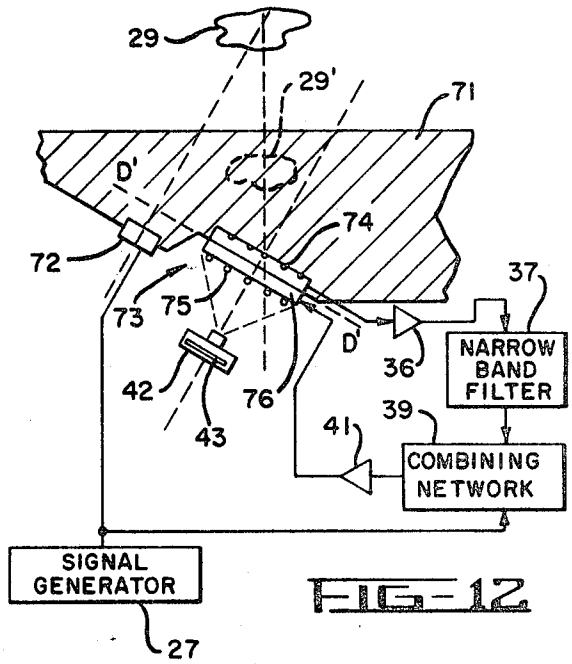


FIG-12

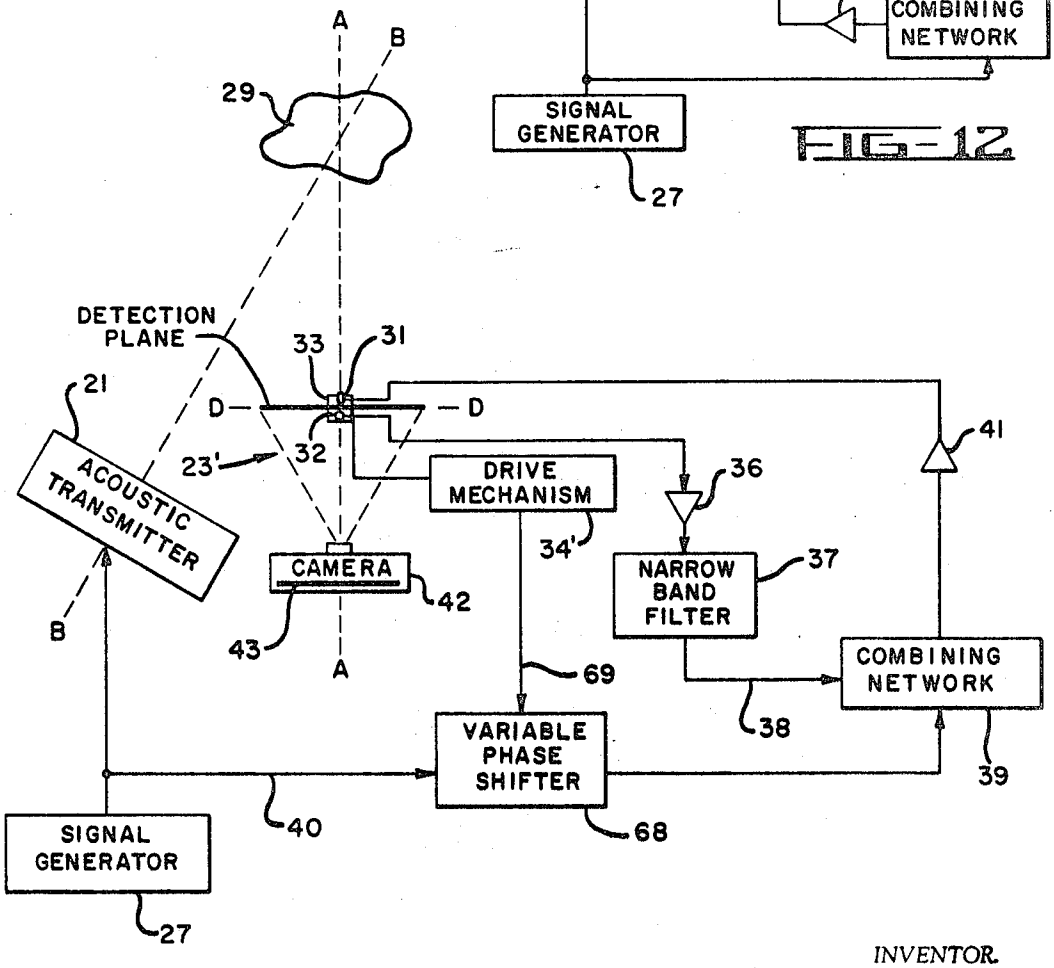


FIG-11

INVENTOR.
GAIL A. MASSEY
BY
ATTORNEY

Sept. 16, 1969 G. A. MASSEY 3,467,216

APPARATUS AND METHOD FOR PRODUCING HOLOGRAMS WITH ACOUSTIC WAVES

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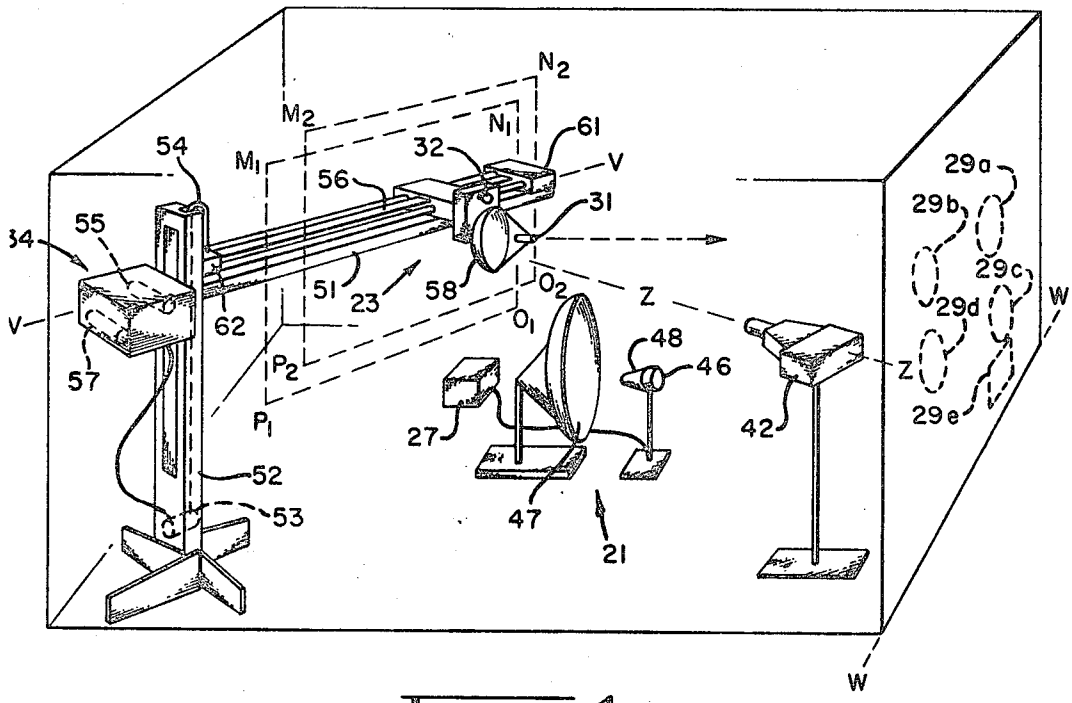


FIG-4

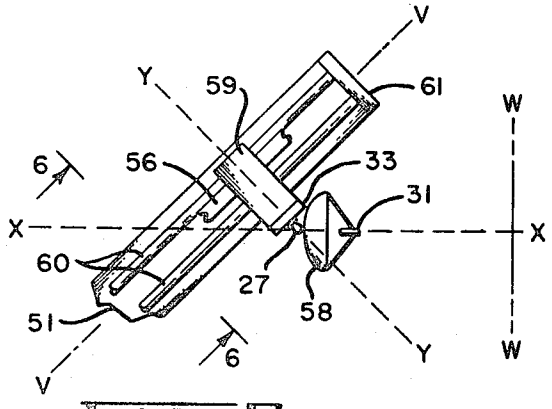


FIG-5

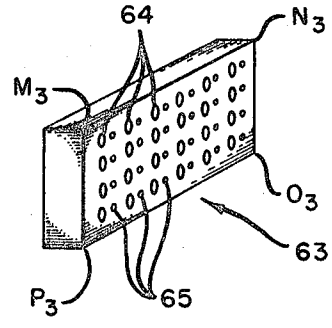


FIG-7

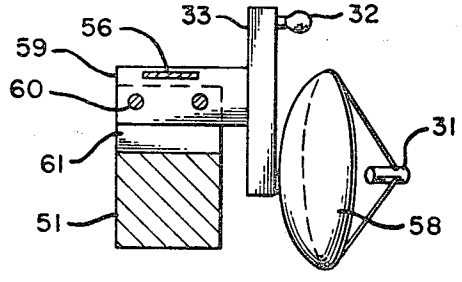


FIG-6

INVENTOR.
GAIL A. MASSEY

BY J. Allen L. Lawler
ATTORNEY

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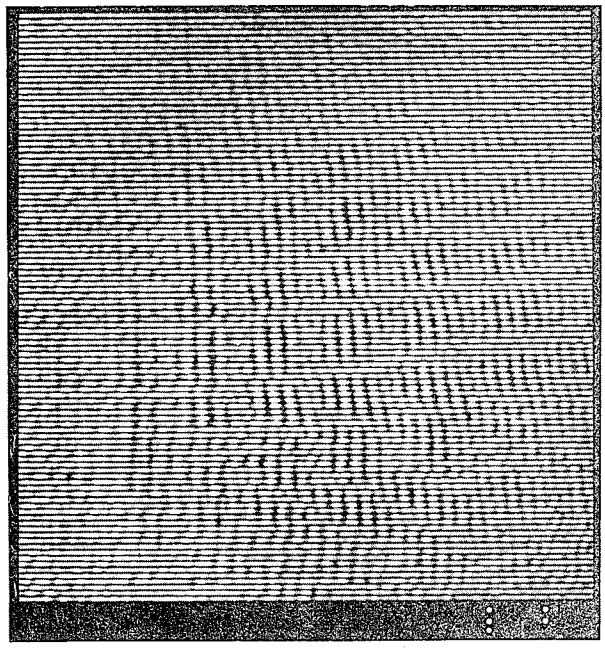


FIG-8

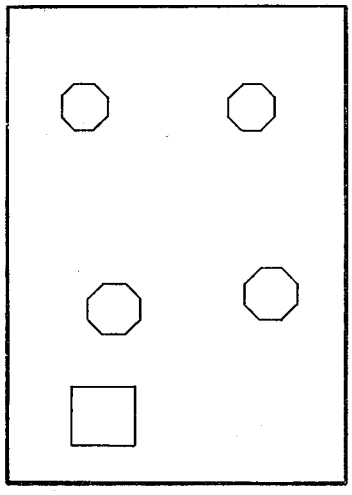


FIG-10

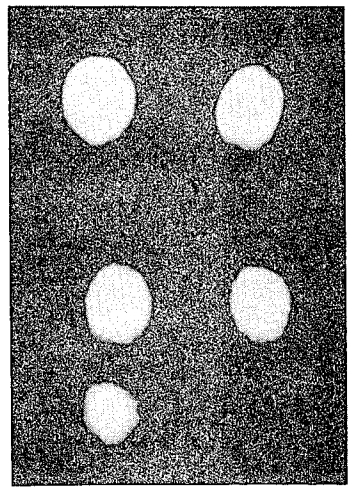


FIG-9

INVENTOR
GAIL A. MASSEY

BY J. Ann T. Gamble
ATTORNEY

United States Patent Office

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Patented Sept. 16, 1969

3,467,216

APPARATUS AND METHOD FOR PRODUCING HOLOGRAMS WITH ACOUSTIC WAVES

Gail A. Massey, Half Moon Bay, Calif., assignor to Sylvania Electric Products Inc., a corporation of Delaware

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Int. Cl. G01v 1/02

U.S. Cl. 181—.5 8 Claims

ABSTRACT OF THE DISCLOSURE

A loudspeaker and a microphone are spaced from a reflecting object and from each other. The microphone transcribes a raster-type scan in a plane that is inclined with respect to a line through the centers of the reflecting object and the scanned area. The output of a signal generator causes the loudspeaker to illuminate the object with acoustic waves. These waves are reflected by the object and are detected by the scanning microphone which produces an output that is combined with the output of the signal generator in a summing network. The combined output signals intensity modulate a lamp which moves with the microphone. The field pattern defined by variations of the light intensity of the lamp is recorded on the photographic plate of a camera. The plate is parallel to the plane area scanned by the microphone. This recording is a hologram of the reflecting object. A visual image of the object is produced by illuminating the developed photographic plate (the hologram transparency) with coherent light from a laser.

BACKGROUND OF THE INVENTION

This invention relates to holography and more particularly to apparatus for and a method of utilizing acoustic signals for producing holograms.

A hologram is a recording of the Fresnel diffraction pattern of an object which may be used to produce a three-dimensional image when the hologram is illuminated with a coherent light signal. Techniques utilizing coherent light generated by a laser are presently available for producing holograms. In certain applications, however, it is desirable to produce an image of objects located in a medium that is substantially opaque to light and other electromagnetic radiation. Such applications include underwater mapping, geological exploration, and imaging through solid objects such as metal walls.

An object of this invention is the provision of improved method and apparatus for producing holograms.

Another object is the provision of method and apparatus for producing holograms of objects located in a medium substantially opaque to electromagnetic radiation.

Another object is the provision of method and apparatus for producing holograms with acoustic waves but without the use of an acoustic reference signal.

SUMMARY OF INVENTION

In accordance with this invention, an electroacoustic transducer is energized by an electrical signal from a signal source to produce acoustic signals which illuminate a reflecting object. Acoustic signals reflected by the object are detected by a plane detector assembly to produce an electrical signal that is combined with an electrical reference signal. The combined signal is processed and recorded to produce a hologram of the object. In one embodiment of the invention the reference signal is obtained directly from the signal source. In a modified form of this invention, acoustic waves reflected by the object are detected in a

plane that is inclined with respect to the direction of propagation of waves from the object, i.e., the detection plane forms an acute angle with the line of propagation of the reflected waves.

DESCRIPTION OF DRAWINGS

This invention will be more fully understood from the following detailed description of preferred embodiments thereof, together with the accompanying drawings in which:

FIGURE 1 is a plan view of a system embodying this invention;

FIGURE 2 is a plan view of a system embodying a modified form of this invention;

FIGURE 3 is a graphic representation of the orientation of the detection plane of the detector assembly;

FIGURE 4 is a perspective view of equipment embodying the system of FIGURE 2;

FIGURE 5 is a plan view of part of the detector assembly shown in FIGURE 4;

FIGURE 6 is an enlarged section of the horizontal boom and detector assembly taken along line 6—6 in FIGURE 5;

FIGURE 7 is a perspective view of an alternate embodiment of the detector assembly;

FIGURE 8 is a photograph of a hologram of the reflecting objects shown in FIGURE 4;

FIGURE 9 is a photograph of the reconstructed images of the objects when the hologram of FIGURE 8 is illuminated by coherent light from a laser;

FIGURE 10 is a drawing illustrating the true shape and arrangement of the reflecting objects which produced the images shown in FIGURE 9; and

FIGURES 11 and 12 are plan views of other systems embodying modified forms of this invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to FIGURE 1, a system embodying this invention comprises an acoustic transmitter **1**, an acoustic reference transmitter **2**, and a detector assembly **3** which are located in a medium **4** that is capable of propagating acoustic or sound waves. The invention may be practiced with a gaseous medium **4**, such as air, that is capable of propagating both acoustic and electromagnetic waves, or with a solid medium such as metal (see FIGURE 12), or a liquid medium, such as water, that support acoustic waves but which are opaque or substantially so to electromagnetic waves.

Acoustic transmitters **1** and **2** are energized by sinusoidally varying electrical signals on lines **5** and **6**, respectively, which are produced by signal generator **7**. Each transmitter comprises an electroacoustic transducer or loudspeaker. Transmitter **1** is positioned such that sound waves **8** generated thereby are directed toward and strike reflecting object **9** which is also located in the medium **4**. Detector assembly **3** is positioned to receive sound waves **8'** reflected by the object. Detector assembly **3** is laterally offset from transmitter **1** and the direction of sound wave propagation along line B—B intersects the line A—A from object **9** to the center of assembly **3** to form an angle α.

Reference transmitter **2** is adjacent to object **9** and is oriented so as to propagate reference waves along line E—E toward detection plane D—D of assembly **3**. Line E—E through the centers of transmitter **2** and assembly **3** intersects line A—A at an angle β.

The detector assembly comprises an electroacoustic transducer or microphone **11** facing the reflecting object and rigidly secured to a support plate **12**. Microphone **11** preferably has a linear frequency response and is oriented such that its longitudinal or focal axis is parallel to line

A—A. Plate **12** is operatively connected to drive mechanism **14** which causes the microphone to transcribe a raster-type scan in the detection plane D—D over an area such as $M_1N_1O_1P_1$ (see FIGURE 4) to detect sound waves reflected from the object. The output of the microphone on line **15** is amplified by amplifier **16** and filtered by narrow band filter **17**. The center frequency of the filter is equal to the frequency of the output of generator **7**, i.e., the frequency of the acoustic signal. The output of the filter is applied to lamp **18** which is also rigidly secured to and moves with plate **12**. The intensity of light from the lamp is preferably a linear function of input power applied to it.

Camera **19** is spaced from the detector assembly and is positioned so that the area scanned by the lamp is within the field of view of the camera. Preferably, the camera and lamp are so positioned that the focal axis of the camera is normal to the plane of movement of the lamp, i.e., the camera axis lies along the line A—A. Photographic plate **20** on which the hologram is recorded is therefore parallel to detection plane D—D.

In operation, the output of signal generator **7** causes loudspeaker **1** to transmit acoustic waves **8** to the reflecting object **9**. Certain of those waves **8'** are reflected by the object back to detection plane D—D. Reference transmitter **2** is responsive to the output of generator **7** for producing sound waves **10** which are also incident on detection plane D—D. Microphone **11** linearly combines or adds reflected waves **8'** and reference waves **10** and produces an electrical signal on line **15** corresponding to the sum. The output of filter **17** intensity modulates lamp **18** and produces an optical field which is the analog of the corresponding acoustic field, resulting in an optical hologram field of the object. Driven by mechanism **14**, the microphone traverses a raster-type scan in the plan D—D and produces a hologram field wholly representative of the object. Camera **19** records a hologram of object **9** on photographic plate **20** which is exposed to the optical field produced by lamp **18**. The nonlinear film response in effect causes the analogs of the reference and reflected waves to be mixed and the recorded trace on the film corresponds to the detected pattern of the reflecting object. An image of the object is produced in the well known manner by illuminating the hologram on plate **20** with coherent light from a laser.

In the system of FIGURE 1, the reference transmitter is located in the medium containing the reflecting object. Although placement of a reference transmitter in the medium may be readily accomplished in a gas, such as air, and in a controlled environment, this may be impracticable where the medium is a solid or solid particles, such as soil, or a liquid such as water, and the reflecting object is inaccessible or unknown. A modified form of this invention which does not require an acoustic reference transmitter is illustrated in FIGURE 2.

Referring now to FIGURE 2, the system comprises an acoustic transmitter **21**, a detector assembly **23**, and a signal generator **27**. Transmitter **21** and generator **27** are the same as the transmitter **1** and generator **7**, respectively, of the system of FIGURE 1.

Detector assembly **23** is similar to detector assembly **3**. Microphone **31** and lamp **32** are rigidly secured to the same side of support plate **33**. Drive mechanism **34** is operatively connected to plate **33** for causing the latter to transcribe a raster-type scan in the detection plane D'—D', and the longitudinal or focal axis of microphone **31** is parallel to the line A'—A' from the object to the center of detector assembly **23** during movement of the microphone. Plane D'—D', however, is inclined at an angle δ with respect to line A'—A'. This angular inclination of the detection plane provides for spatial separation of the real, virtual, and zero-order images in the reconstruction process. The spatial frequency of a field that varies sinusoidally in amplitude along a given direction in a detection plane is the reciprocal of the distance corresponding to the spatial period of the variation. For propagating waves, changing the relative angle of arrival of the wave at the detection plane changes the spatial period and therefore the spatial frequency.

Referring now to FIGURE 3, the spatial frequency f_o of acoustic waves incident on detection plane D'—D' at the angle δ is representable as $f_o = 1/\lambda_o \sin \gamma$ wherein λ is the wavelength of the acoustic waves and γ is the angle between detection plane D'—D' and line A'—A'.

Generally, a complex field can be described by a spectrum of spatial frequencies corresponding to a set of waves arriving at different angles. If all the angles lie within a cone with an apex half-angle less than 90°, this spectrum is said to be band limited. Such a spatial signal can be frequency translated by changing the average angle of arrival relative to the detection plane. If the original cone were centered about the normal to the plane, spatial translation to a new angle θ would correspond to imposing the old variation as a spatial "envelope modulation" on a new "carrier" of spatial frequency $f=\sin \theta/\lambda$, where λ is the wavelength. When spatial frequency translation is effected in recording a hologram, the diffraction components produced in the reconstruction process are therefore angularly displaced relative to each other; thus, the real and virtual images, as well as the zero order beam, do not overlap.

The output of microphone **31** on line **35** is amplified by amplifier **36** and filtered by narrow band filter **37**. The bandwidth of filter **37** is centered at the frequency of the output of transmitter **21**. The output of filter **37** is applied on line **38** to combining network **39**. The output of generator **27** is also applied on line **40** to the second input to network **39**. The combining network may, by way of example, be a summing amplifier. The output of network **39** is amplified by amplifier **41** and is applied to lamp **32**.

Camera **42** is also spaced from the detection plane with its lens facing lamp **27**. The longitudinal or focal axis of camera **42** preferably extends in a direction perpendicular to detection plane D'—D' and intersects line A'—A' at the angle γ. Photographic plate **43** (the hologram recording plane) is parallel to the detection plane D'—D'.

In operation, the output of generator **27** causes transmitter **21** to illuminate the reflecting object with acoustic waves. Reflected sound waves incident on assembly **23** are detected by microphone **31**. The detected signals are then combined in network **39** with the electrical reference signal on line **40**. The output of network **39** is applied to lamp **32** and intensity modulates it to provide a light signal representative of the acoustic field of the reflecting object. Mechanism **34** drives the microphone and lamp in a raster-type scan over detection plane D'—D'. The lamp exposes plate **43** and makes a permanent record or hologram of the fields produced by the reflecting object. As before, an image of the object is reconstructed by illuminating the hologram with coherent light.

Equipment embodying the system of FIGURE 2 and which was actually built and tested is illustrated in FIGURE 4. Transmitter **21** comprises loudspeaker **46** located at the focal point of parabolic reflector **47**. A metallic cone **48** connected to loudspeaker **46** directs acoustic signals from the latter to illuminate reflector **47**. The aperture of the reflector faces reflecting objects **29***a–e*.

Detector assembly **23** and drive mechanism **34** are supported on opposite ends of horizontal boom **51** which is connected for vertical movement to column **52**. Such movement of boom **51** is controlled by drive motor **53** operatively connected to the boom by flexible drive cable **54** which extends through column **52**. Horizontal movement of assembly **23** is controlled by drive motor **55** which is connected to the detector assembly by tape **56**. Servo **57** controls the operation of motors **53** and **55** to

synchronize vertical and horizontal movement of the parts and produce the desired raster scan of the microphone and lamp.

Referring now to FIGURES 5 and 6, detector assembly **23** comprises parabolic reflector **58** connected to plate **33**. Microphone **31** is supported at the focal point of reflector **58**. The microphone faces reflector **58** and received signals reflected from it. Lamp **32** is also supported by plate **33** and is located above the microphone and reflector. Plate **33** is connected to guide **59**. Guide bars **60** extend through and support the guide above boom **51**. The guide bars are suspended between stop plates **61** and **62** which are connected to opposite ends of boom **51**. Tape **56** extends through and is secured to guide **59**.

Boom **51** is positioned such that the longitudinal axis V—V thereof is at an acute angle with respect to the plane W—W containing objects **29**. The focal axis X—X of microphone reflector **58**, however, is perpendicular to the plane W—W. The optical axis Z—Z of camera **42** is perpendicular to the plane of movement of lamp **32** which is parallel to the longitudinal axis V—V of the boom.

Servo **57** causes the detector assembly (microphone **31**, reflector **58**, and lamp **32**) to traverse a raster-type scan. Motor **55** causes microphone **31** to scan horizontally, for example, from a point on line M_1P_1 to a point on line N_1O_1, see FIGURE 4. When guide **59** contacts a microswitch (not shown) at plate **61**, the servo causes motor **53** to incrementally shift the vertical position of boom **51**. The servo then reverses the polarity of the signal applied to motor **55** to scan the microphone from a point on line N_1O_1 to a point on line M_1P_1. This operation is repeated until the microphone transcribes the area $M_1N_1O_1P_1$. Alternatively, the lamp **32** may be electrically disconnected from the combining circuit and the polarity of the signal applied to motor **55** reversed to move the microphone back to the line M_1P_1 before the motor **53** is energized to change the vertical position of the boom **51**. Since lamp **32** is offset from microphone **31** and is also connected to plate **33**, the lamp scans an area $M_2N_2O_2P_2$ similar to that scanned by the microphone. The intensity of light from the lamp at each point in the scanned area corresponds to the characteristics of the signal received by the microphone. Thus, lamp **32** produces an optical field which is the analog of the acoustic field produced by the reflecting objects.

Alternatively, the detector assembly may be a fixed array **63**, see FIGURE 7, comprising a plurality of individual microphones **64**. The microphones are arranged in rows that extend over the area $M_3N_3O_3P_3$ and thus acoustically sensitize it. The signal detected by each microphone is correlated with its position in the array and is combined with the electric reference signal for application to an associated lamp **65** to produce the hologram of the objects.

In laser holography, optical detection by photographic film is approximately a square law phenomenon and therefore requires a laser reference beam to determine the relative phase of the reflected and reference signals. As disclosed by E. N. Leith and J. Upatneiks, Journal of the Optical Society of America, vol. 52, No. 10, pp. 1123–1130, October 1962, however, the laser reference beam is offset from the laser beam reflected by the object to provide spatial frequency translation of the zero order and virtual and real images of the objects. This technique is employed in the system of FIGURE 1 wherein the acoustic reference beam (line E—E) makes an angle β with the normal A—A to the detection plane D—D.

It has been discovered that in acoustic holography, however, the signals may be separately or individually linearly detected and then combined to produce a signal representative of the incident acoustic field. Thus, an electric reference signal, in place of an acoustic reference signal, may be combined with the detected signal reflected from an object. Such a system is illustrated in FIGURE 2.

In order to provide for separation of the diffracted images in the reconstruction process, the detection plane D'—D' of the system of FIGURE 2 is inclined with respect to the line A'—A'. Referring now to FIGURE 2, the detected signal from microphone **31** is representable as

$$U(x,y)=K_1U_{sig}(x,y)e^{j2\pi f0x} \quad (1)$$

where $U_{sig}(x,y)$ is the acoustic field that would be present at the detection plane D'—D' if the incline angle were zero, K_1 is the transfer characteristic of microphone **31**, $e^{j2\pi f0x}$ is the variation of the acoustic field introduced by inclining the detection plane D'—D' and f_o is the spatial frequency introduced in the scanning plane by the tilt. For simplicity, the exponential term representing the sinusoidal time variation of the output of transmitter **21** is omitted from these equations. Referring now to FIGURE 3, f_o is the spatial frequency produced by inclining the detection plane by the angle $\gamma=\sin^{-1}(\lambda_0 f_0)$ with respect to the normal to the line A'—A', wherein λ_0 is the wavelength of sound waves produced by loudspeaker **21**.

The reference signal on line **40** from generator **27** (FIGURE 2) is a sinusoidal time-varying signal having a complex amplitude A. If network **39** is a summing amplifier, the power output thereof is representable as

$$P(x,y)=K_2[A+K_1U_{sig}(x,y)e^{j2\pi f0x}][A^*+K_1{}^*U_{sig}{}^*(x,y)e^{-j2\pi f0x}] \quad (2)$$

$$=K_2[|A|^2+K_1|U_{sig}(x,y)|^2+A^*K_1U_{sig}(x,y)e^{j2f0x}+AK_1{}^*U_{sig}{}^*(x,y)e^{-j2\pi f0x}] \quad (3)$$

If the lamp intensity varies linearly with input power, $I(x,y)$, the optical intensity used to expose the film, is then proportional to $P(x,y)$. When the developed hologram transparency is exposed to a plane wave of monochromatic light, the transmitted optical field amplitude is also proportioned to $P(x,y)$ in Equation 3. In that case, the first term of Equation 3 defines a group of transmitted waves propagating along the normal to the hologram axis along the direction of the incident wave. The second and third terms of Equation 3 define groups of waves propagating off the axis and along or centered about the angles $\pm \sin^{-1}(\lambda_0 f_0)$ away from the normal. These terms represent the transmitted waves which produce the spatially separated virtual and real images, respectively, of the reflecting object. If the inclination of the detection plane corresponding to the constant f_0, were not present, all the waves would be on the axis and the images would overlap.

By way of example, FIGURE 8 is a photograph of a hologram of objects **29***a–e* produced by the system of FIGURE 4 which had the following dimensions, components and characteristics:

Reflecting objects:

29a–d:	
Shape	Octagonal.
Material	Aluminum.
Width	15 cms.
29e	
Shape	Square.
Material	Aluminum.
Width	19 cms.
Spacing (objects 29 to plane D'—D')	5 meters.
Scan area $M_1N_1O_1P_1$	1 sq. meter.
Raster spacing	1 cm.
Sound waves 8 wavelength	1 cm.
Average sound level (at plane D'—D')	0.05 microbars.
Medium	Air.

In order to reduce reflection of sound waves from the walls adjacent the objects, sheets of foam rubber (not shown) were placed behind the objects. The hologram of

the objects was recorded on the photographic plate **43** in the manner described above. The film was then photographically reproduced to a positive transparency 0.5 cm. square. This transparency was illuminated by a laser beam operating at **6328** A. FIGURE 9 is a photograph of reconstructed images of the objects produced by illuminating the hologram with a laser beam. FIGURE 10 is a scale drawing of the objects **29** that are illustrated in FIGURE **9**. A modified form of the invention providing for spatial frequency translation of the zero order and real and virtual images of the objects and wherein the detection plane D—D is normal to the center line A—A of the detector assembly is illustrated in FIGURE 11. This system is similar to the system of FIGURE 2 except that the inclination of detection plane D—D is zero and variable phase shifter **68** is connected in series between the output of generator **27** and the associated input of network **39**. An output of the drive mechanism **34'** on line **69** is applied to and controls the operation of the phase shifter. This bias signal causes the phase shifter to vary the phase of the reference signal on line **40** an amount corresponding to the term $e^{j2\pi f_0 x}$ which is representative of the spatial frequency translation produced by tilting the detection plane D'—D' in the system of FIGURE 2.

The systems described above operated in air, a fluid which propagates both acoustic and electromagnetic waves. This invention is not limited to operation in such a medium, however, and operates in association with media such as the earth or metal walls which propagate acoustic waves more effectively and efficiently than electromagnetic waves. This invention also operates in association with a liquid fluid such as water which propagates acoustic waves. The system of FIGURE 12 is similar to the system of FIGURE 2 except that a medium **71** that is substantially opaque to electromagnetic waves but which propagates acoustic waves is spaced between the reflecting object **29** and the acoustic transmitter **72** and detector assembly **73**.

The medium **71** may, by way of example, be a metal wall. Transmitter **72** comprises a piezoelectric loudspeaker which is bonded to the surface of the wall. Detector assembly **73** is similar to the assembly **65** of FIGURE 7. Microphones **74** are piezoelectric microphones that are bonded to the surface of the wall. The lamps **75** are located on the opposite side of support block **76** from the microphones and face camera **42**.

The medium **71** may also be water which is substantially opaque to electromagnetic radiation and contains a reflecting object **29'**. Transmitters **72** and microphones **73** are then subaqueous devices that are located in the water. The thickness of block **76** is preferably sufficient to position the lamps **75** outside of the water.

Although this invention is described in relation to preferred embodiments thereof, changes, improvements, and modifications thereof will be apparent to those skilled in the art without departing from the spirit of the invention.

What is claimed is:

1. A system utilizing acoustic waves for making a hologram of an object comprising

an electric signal generator,

an acoustic wave transmitter energized by said generator and oriented to direct acoustic waves toward said object whereby said waves are reflected from said object,

an acoustic wave propagating medium between said transmitter and said object,

detecting means responsive to said reflected waves over a predetermined field for producing electrical signals corresponding to the pattern of said waves in said field,

said predetermined field being in a plane which forms an acut angle with a line from the object to the center of the field,

said detecting means comprising a detector assembly oriented generally parallel to said field and coextensive therewith,

means for combining the outputs of said detecting means and said generator, and

means responsive to the outputs of said combining means for producing a hologram of the object.

2. The system according to claim **1** in which said hologram producing means comprises

a lamp connected to the output of said combining means and producing light which varies in intensity with changes in the output of said combining means, and

means for permanently recording the variations in the intensity of said light.

3. The system according to claim **1** in which said detector assembly comprises

a microphone, and

means for moving said microphone in a raster-type scan over said field.

4. The system according to claim **3** in which said recording means comprises a lamp supported for movement with said microphone.

5. The system according to claim **4** with a permanent recording means comprising a light sensitive plate in a plane parallel to the plane of movement of said lamp.

6. The system according to claim **1** in which said detector assembly comprises an array of microphones in the plane of and coextensive with said field and said hologram producing means comprises

a plane array of lamps responsive to the outputs, respectively, of said microphones for producing light, the intensity of light from each lamp being proportional to the output of the microphone associated therewith, and

a plane photographic plate disposed parallel to the plane of the lamp array.

7. A system utilizing acoustic waves for making a hologram of an object comprising

an electric signal generator,

an acoustic wave transmitter energized by said generator and oriented to direct acoustic waves toward said object whereby said waves are reflected from said object,

an acoustic wave propagating medium between said transmitter and said object,

detecting means responsive to said reflected waves over a predetermined field for producing electrical signals corresponding to the pattern of said waves in said field, said detecting means comprising

a microphone, and

means for moving said microphone in a raster-type scan over said field,

means responsive to an output of said generator and an output of said microphone moving means for shifting the phase of the output signal from said signal generator,

means for combining the outputs of said detecting means and said phase shifting means, and

means responsive to the outputs of said combining means for producing a hologram of the object.

8. The method of making a hologram of an object with acoustic waves consisting of the steps of

energizing an acoustic wave transmitter with the output of a reference generator,

illuminating the object with acoustic waves from said transmitter,

detecting acoustic waves reflected by said object over a plane field transverse to the direction of propagation of the reflected waves by moving a microphone in a raster type scan over a plane disposed at an

acute angle to a line from the object to the center of the field and producing an electrical signal analogous to the pattern of acoustic waves over the field,

combining said electrical signal with the output of said generator,

moving a light source in synchronism with said microphone,

modulating the intensity of the light output of the light source with the combined electrical signal and reference generator output, and

exposing a light sensitive material to light from said source and recording the variations in light intensity over an area corresponding to that of said field.

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BENJAMIN A. BORCHELT, Primary Examiner

G. H. GLANZMAN, Assistant Examiner

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