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Barkhoudarian et al.

[11] **3,879,700**

[45] **Apr. 22, 1975**

[54] **DEVICE FOR CONVERTING AN ACOUSTIC PATTERN INTO A VISUAL IMAGE**

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[73] Assignee: **The Bendix Corporation,** Teterboro, N.J.

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[21] Appl. No.: **314,313**

[52] **U.S. Cl.**......... **340/5 MP;** 73/67.5 H; 178/7.5 D; 313/65 R; 340/5 H

[51] **Int. Cl.** **H04b 11/00**

[58] **Field of Search** ..... 340/5 MP, 5 H, 15; 315/11, 315/12; 313/65 R, 92 R; 73/67.5 H; 178/7.5 D, DIG. 18

[56] **References Cited**

UNITED STATES PATENTS

2,739,243	3/1956	Sheldon	350/5 MP
2,816,236	12/1957	Rosen	340/5 MP X
2,855,531	10/1958	Nicoll	340/5 MP X
2,903,617	9/1959	Turner	340/5 MP X
3,243,508	3/1966	Sclar	340/5 MP X
3,505,558	4/1970	Jacobs	340/5 MP X
3,603,828	9/1971	Sheldon	313/65 R
3,622,825	11/1971	Bennett	340/5 MP X
3,675,028	7/1972	Grant	315/11 X
3,716,740	2/1973	Crowell et al.	315/11
3,742,284	6/1973	Sackman	340/5 MP X

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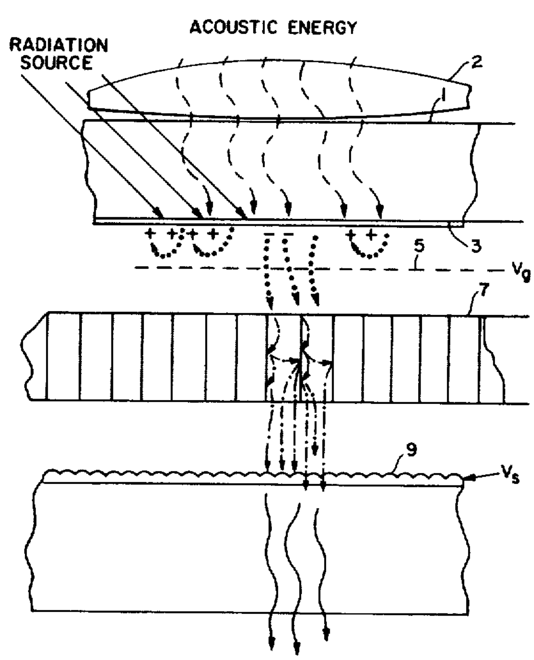
[57] **ABSTRACT**

An acoustic pattern imaged on a piezoelectric transducer is converted to an electronic charge pattern. A source of electrons, such as a photocathode illuminated by a radiation source, is closely associated with the transducer and electrons are liberated in accordance with the pattern. The electrons are multiplied by a microchannel plate electron multiplier and are converted into photon energy by a phosphor screen to provide a visual image of the acoustic pattern. A grid is positioned between the piezoelectric transducer and the microchannel plate electron multiplier and is maintained at a potential so that the average electron current varies in accordance with the acoustic input.

20 Claims, 6 Drawing Figures



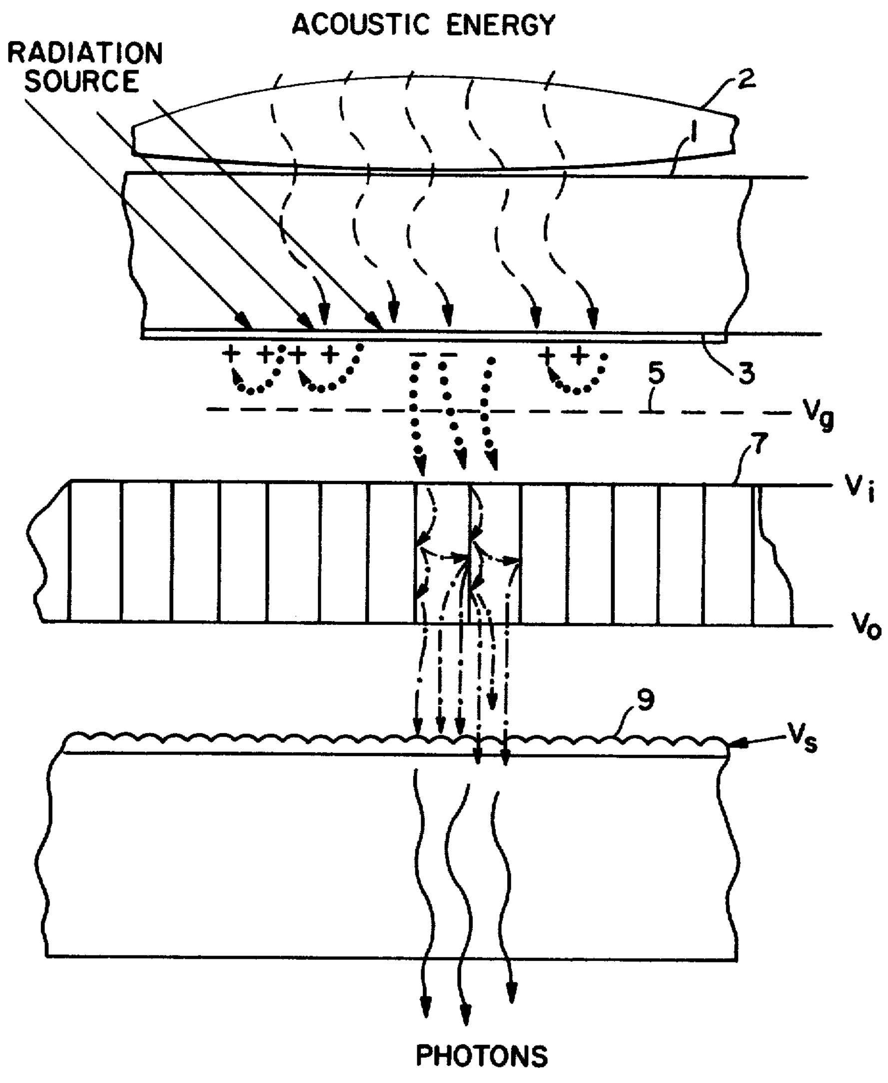

ACOUSTIC ENERGY
RADIATION SOURCE
2
1
3
5
V_g
7
V_i
V_o
9
V_s
PHOTONS

FIG. 1

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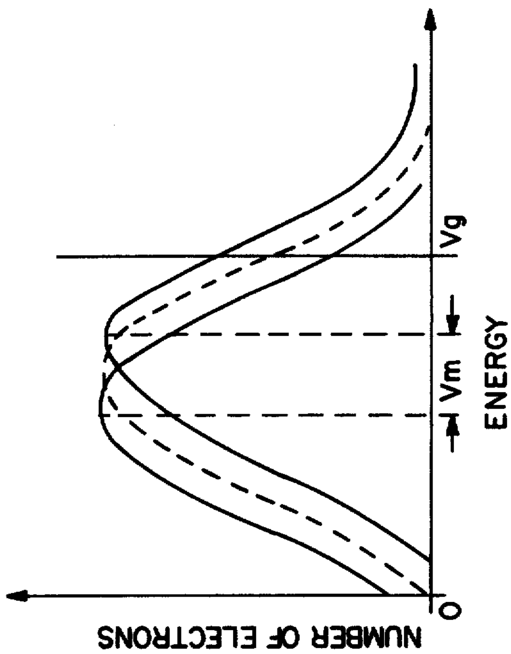

FIG. 2

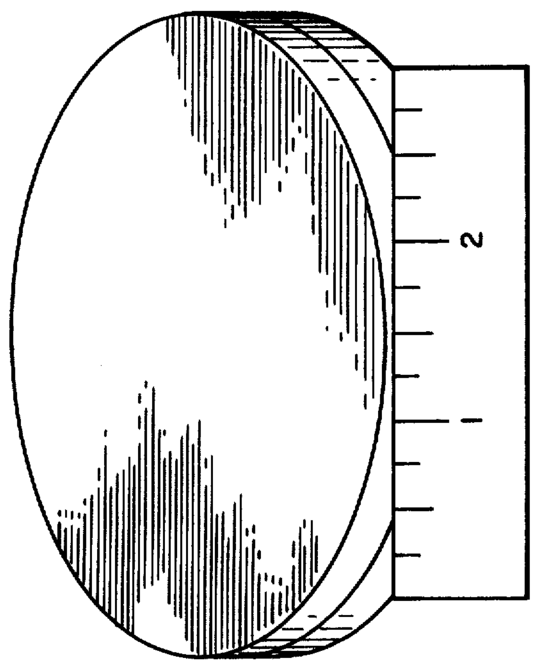

FIG. 5

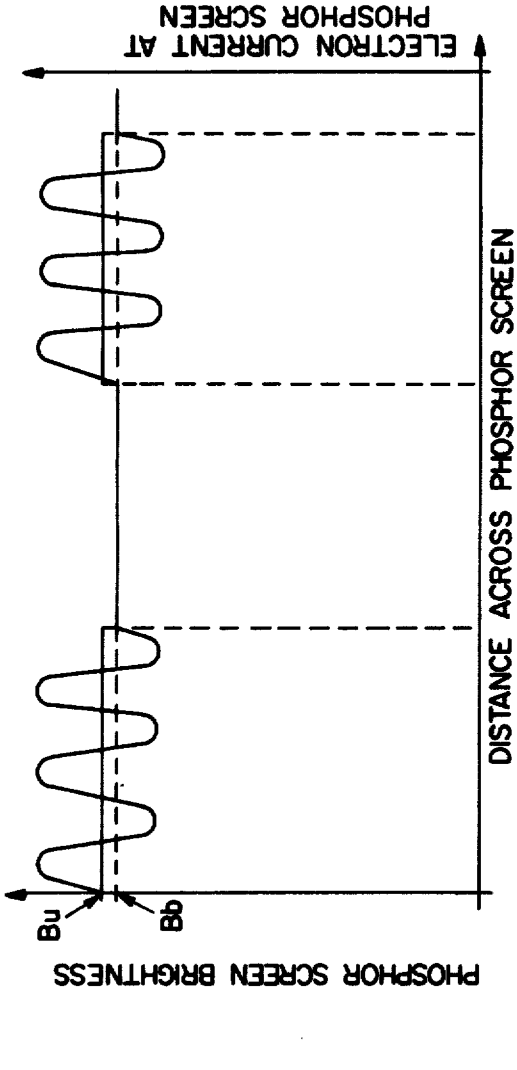

FIG. 4

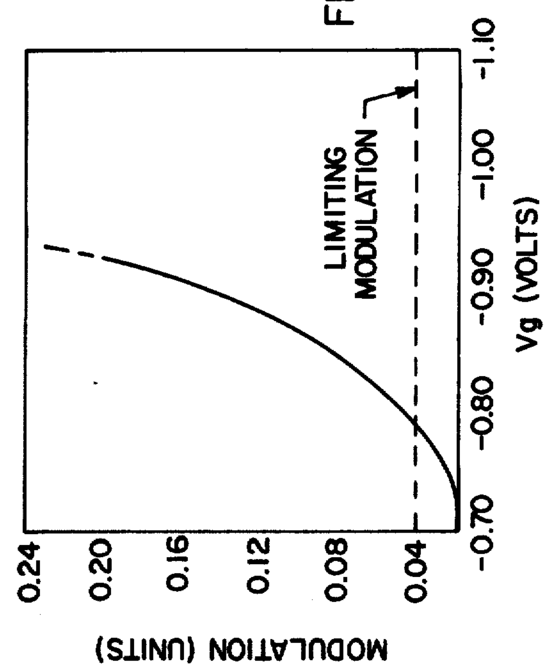

FIG. 6

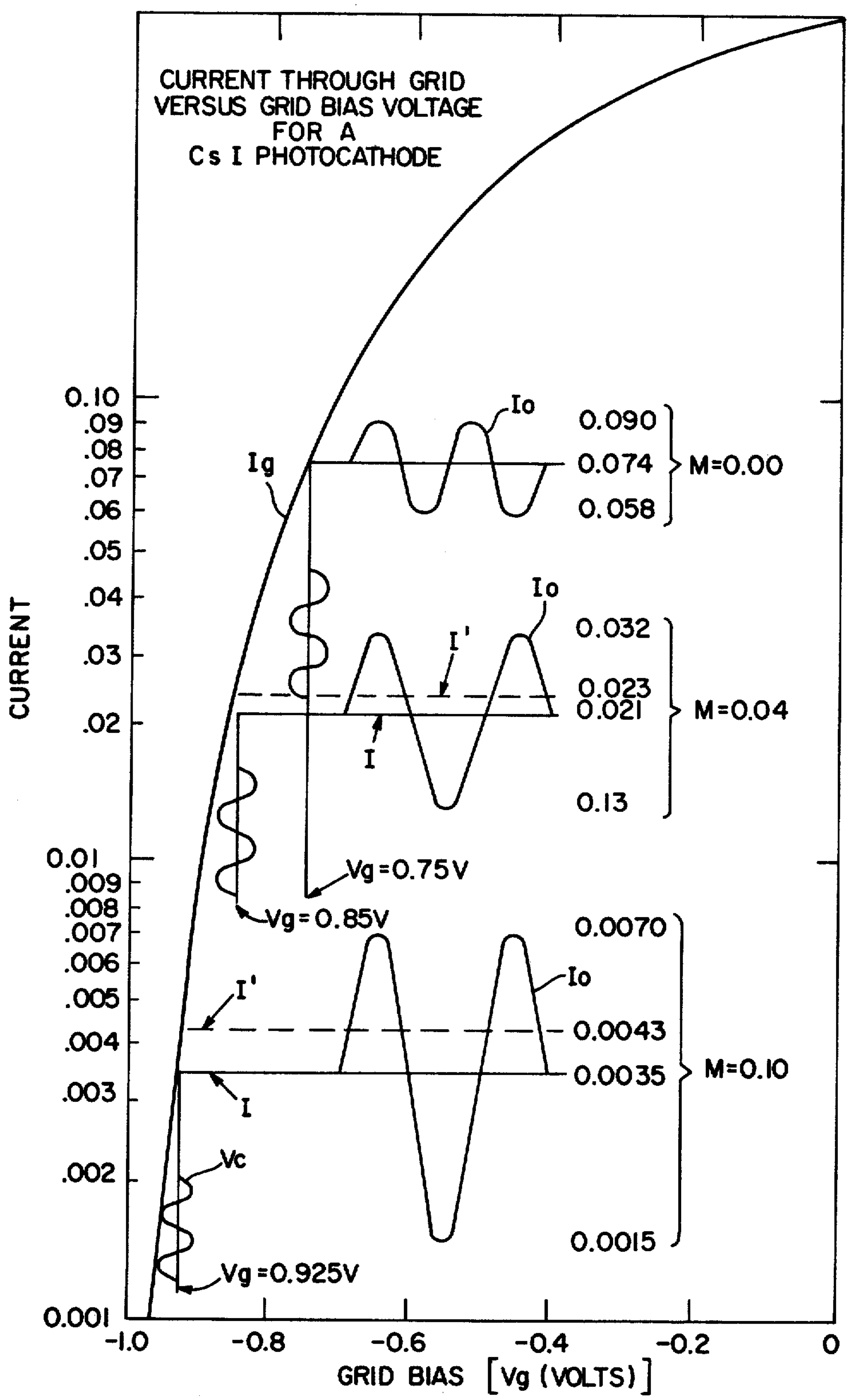
CURRENT THROUGH GRID
VERSUS GRID BIAS VOLTAGE
FOR A
Cs I PHOTOCATHODE
CURRENT
0.10
.09
.08
.07
.06
.05
.04
.03
.02
0.01
.009
.008
.007
.006
.005
.004
.003
.002
0.001
-1.0
-0.8
-0.6
-0.4
-0.2
0
GRID BIAS [Vg (VOLTS)]
Ig
Io
0.090
0.074
0.058
M=0.00
I'
I
0.032
0.023
0.021
0.13
M=0.04
Vg=0.75V
Vg=0.85V
0.0070
0.0043
0.0035
0.0015
M=0.10
Vc
Vg=0.925V

FIG. 3

DEVICE FOR CONVERTING AN ACOUSTIC PATTERN INTO A VISUAL IMAGE

The invention relates to a device for converting an acoustic pattern to a visual image.

Devices as used heretofore for converting an acoustic pattern to a visual image used an electron gun for scanning the acoustic pattern and the resulting current was amplified and converted to a visual picture using scanning techniques. Such a device was complicated and relatively large in size and required adequate power to operate.

The present application is an improvement on copending application Ser. No. 314,314 assigned to the same assignee as the present application and provides an improved visual image by biasing the electron current so that the average electron current varies in accordance with the acoustic input.

The invention contemplates a device for converting an acoustic pattern into a visual image, comprising a piezoelectric transducer for receiving the acoustic pattern and providing an electronic charge pattern corresponding thereto, a source of electrons associated with the piezoelectric transducer for providing an electron current, means for biasing the electron current so that the electronic charge pattern modulates the electron current to provide an average electron current which varies in accordance with the acoustic input, a microchannel plate electron multiplier for amplifying the modulated electron current, and means for converting the amplified electron current to a visual image corresponding to the acoustic pattern.

One object of the present invention is to provide a device for converting an acoustic pattern to an electrical current pattern directly without the use of an electron gun or video processing.

Another object of the invention is to provide a device for converting an acoustic pattern into an electron current pattern for remote readout, that is, display and/or storage.

Another object of the invention is to use a piezoelectric transducer for providing an electronic charge or voltage pattern corresponding to an acoustic pattern imaged on the piezoelectric transducer.

Another object of the invention is to provide a spatial electron current modulated by the voltage pattern by illuminating a photocathode from a radiation source and using a microchannel plate electron multiplier for amplifying the electron current.

Another object is to utilize a phosphorous screen for converting the amplified electron current to photon energy to provide a visual image of the acoustic pattern.

A more specific object of the invention is to bias the electron current so that the electron current is modulated by the acoustic pattern to provide an average electron current which varies in accordance with the acoustic input.

These and other objects and advantages of the invention will appear more fully hereinafter from a consideration of the detailed description which follows, taken together with the accompanying drawings wherein one embodiment of the invention is illustrated by way of example. It is to be understood, however, that the drawings are for the purpose of illustration only and are not a definition of the limits of the invention, reference being had to the appended claims for this purpose.

In the drawings, FIG. 1 is a schematic diagram of a device constructed according to the invention for converting an acoustic pattern to a visual image.

FIG. 2 shows the energy distribution of electrons emitted from a Cesium Iodide photocathode,

FIG. 3 shows the electron current at the input of each channel in the microchannel plate electron multiplier from a Cesium Iodide photocathode plotted as ordinate in logarithmic scale and bias voltage plotted linearly as abscissa.

FIG. 4 is a schematic diagram showing the phosphorous screen brightness distribution resulting from a square wave acoustic pattern,

FIG. 5 is a perspective view of a device constructed according to the invention, and

FIG. 6 shows how modulation varies as a function of grid bias.

Referring to the drawings, a novel converter constructed according to the invention is shown in FIG. 1 as comprising a piezoelectric transducer **1**, such as a quartz crystal or barium titanate ceramic. An acoustic pattern, shown by broken line arrows, is imaged by an acoustic lens **2** on the piezoelectric transducer and a corresponding electronic charge or voltage pattern is formed on the transducer as shown by the plus and minus signs. The transducer has a photocathode **3** associated therewith, preferably on one surface, and the photocathode is uniformly illuminated by a radiation source, such as ultraviolet, infrared, electromagnetic or radio active, as shown by the solid line arrows. The photocathode may be Cesium Iodide which has a non-linear electron energy distribution.

The irradiated photocathode **3** is a source of photoelectrons, and electrons are released from the photocathode having a spatial distribution of electron energies corresponding to the acoustic input pattern.

A grid in the form of a fine mesh **5** is positioned adjacent the photocathode and is maintained at a potential V_g to provide an average electron current I' which varies in accordance with the acoustic input. The grid voltage may vary between approximately eight tenths (0.8) volt and 0.950 volt below the potential of the piezoelectric transducer and photocathode which may be at ground potential. With this arrangement grid **5** passes the higher energy electrons and repels the lower energy electrons as shown by the dotted line arrows and the electron current passing through the grid is modulated by the acoustic pattern and has an average value which varies in accordance with the acoustic input. The modulated electron current is linearly amplified by a microchannel plate electron multiplier **7**, as shown by the dash-dot arrows, and the spatially distributed current from the microchannel plate is imaged on a high potential phosphorous screen **9** where it is converted to photon energy to provide a visual image of the acoustic pattern.

The input potential V_i of the microchannel plate is maintained at about 300 volts higher than the grid potential V_g and the output potential V_O of the microchannel plate electron multiplier is adjusted to give the required gain and may be approximately 1,000 volts higher than V_i. The phosphorous screen potential V_s is about 5,000 volts higher than V_O.

In some instances it may be desirable to avoid using a separate grid in the form of a fine mesh and instead maintain the input face of the microchannel plate at the potential V_g to modulate the electron current as described above. FIG. 2 shows the non-linear energy distribution of electrons emitted from an irradiated Cesium Iodide photocathode. The number of electrons is plotted as the ordinate and the energy of the electrons is plotted as the abcissa. The dotted line shows the energy distribution of the electrons in the absence of an acoustic pattern and the solid lines show the energy distributions of the electrons when modulated by the acoustic pattern with a maximum variation of V_m volts. Electron currents correspond to the areas under the curves. The grid potential V_g preferably is selected so that modulation of the electron current from the photocathode by the electronic charge pattern occurs in the non-linear region of the curves so that the average electron current I' varies in accordance with the acoustic input.

In FIG. 3 the electron current I_g through the grid for each element of the Cesium Iodide photocathode is plotted in logarithmic scale as the ordinate for various grid bias voltages V_g plotted in linear scale as the abcissa. With a grid voltage of 0.925 volts and an input sine voltage V_r from the quartz crystal having am amplitude and frequency of the acoustic input, an electron output current I_o which varies from 0.0015 to 0.0070 passes through the grid.

The average electron current I' shown by the dotted lines has a value of 0.0043. The current I shown by the solid line has a value of 0.0035 and is the average current when the input voltage V_r from the quartz crystal is zero, that is, I is the average current without an acoustic input. The modulation M is 0.10 and is given by the following equation:

$$M = \frac{I' - I}{I' + I} \quad (1)$$

The greater the modulation for a given acoustic input the better will be the contrast of the visual image on the phosphor screen. Preferably the acoustic-wave-induced piezoelectric modulation voltage, the grid bias potential, the wavelength distribution of the radiation source, and the emitted electron energy distribution is chosen to maximize the difference between I' and I. However, a suitable balance must be maintained between tube brightness as determined by the average electron current I and the modulation.

In a second example in FIG. 3 the grid voltage V_g is 0.85 volts and the electron current I_o varies between 0.032 and 0.013 and the average electron current I' is 0.023. In this example I equals 0.021 and M is equal to 0.04.

In a third example the grid voltage V_g is 0.75 volts and the electron current I_o varies between 0.090 and 0.058. In this case the average current I' is the same as I and is equal to 0.074 and the modulation M is zero.

These examples indicate and FIG. 6 shows that the modulation M increases as the grid bias V_g increases negatively. Even greater modulation M and better contrast can be obtained by increasing the negative bias V_g so that the lower portions of the electron current I_o are cut off to increase the difference between the average currents I' and I. This can be done by increasing V_g negatively to about 0.950 volts.

In the first two examples above, the grid voltages are selected so that modulation of the electron current by the acoustic input occurs on the non-linear portion of the electron current curve and M is greater than zero. However, in the last example modulation occurs on the linear portion of the curve and M equals zero so that little or no resulting contrast would appear on the phosphorous screen.

The phosphorous screen brightness distribution for a square wave acoustic pattern is shown in FIG. 4. The waves show the instantaneous electron current to the phosphorous screen due to acoustic modulation and the amplitude and frequency of the acoustic input. The average screen brightness due to emission produced by the radiation source and modulation of the electron current by an acoustic input is shown by the line B_u and the screen brightness due to photocathode emission produced by the radiation source only is shown by the line B_b. The resulting modulation (M) in the phosphor screen brightness (FIG. 4) is given by the equation:

$$M = (B_u - B_b) / (B_u + B_b) \quad (2)$$

Where B_u is the average screen brightness due to emission produced by the radiation source and modulation of the electron current in the presence of the acoustic input, and B_b is screen brightness due to photocathode emission produced by the radiation source only.

The acoustic pattern may have any desired frequency (such as subsonic, sonic or ultrasonic) given by the equation:

$$f_a = (2\nu/\lambda) \quad (3)$$

Where ν is the propagation velocity and λ is the acoustic wavelength in the piezoelectric material.

The conductivity of the photocathode should be great enough to allow the photocathode current to remain at equilibrium with the piezoelectric modulation potential, but small enough to eliminate image quality degradation due to charge conduction. The values of the volume resistivity (ρ) and permitivity (ϵ) of the photocathode material should be such that the characteristic time constant (γ) of the photocathode is much larger than the applied acoustical period:

$$\nu = \rho\epsilon >> 1/f_a \quad (4)$$

Where f_a is the applied acoustical frequency.

A device constructed according to the invention for converting an acoustic pattern into a visual image may be packaged in an evacuated circular envelope as shown in FIG. 5. The envelope need not be more than several inches in diameter and less than an inch thick. In some instances it may be desirable to incorporate the device in a compact package, e.g., goggles, for underwater detection of acoustic patterns.

With the present arrangement no electron gun or video processing of the electronic signal produced by the acoustic image converter is required. A direct-view visual image of an acoustic input image is produced at the phosphorous screen.

What is claimed is:

1. A device for converting an acoustic pattern into a visual image, comprising a piezoelectric transducer for receiving the acoustic pattern and providing an electronic charge pattern corresponding thereto, a source of electrons associated with the piezoelectric transducer for providing an electron current, means for bias-

ing the electron current at a potential to provide an electron current modulated by the electronic charge pattern and having an average which varies in accordance with the acoustic pattern, a microchannel plate electron multiplier for amplifying the modulated electron current, and means for converting the amplified electron current to a visual image corresponding to the acoustic pattern.

2. A device for converting an acoustic pattern into a visual image as described in claim **1** in which the means for biasing the electron current includes a grid positioned between the electron emitting means and the microchannel plate electron multiplier.

3. A device for converting an acoustic pattern into a visual image as described in claim **2** in which the grid is a fine mesh.

4. A device for converting an acoustic pattern into a visual image as described in claim **1** in which the piezoelectric transducer is arranged relative to the source to release electrons from the source with a spatial distribution of electron energies corresponding to the acoustic pattern.

5. A device for converting an acoustic pattern into a visual image as described in claim **1** in which the source of electrons includes a photocathode and a radiation source for irradiating the photocathode.

6. A device for converting an acoustic pattern into a visual image as described in claim **1** in which the image converting means comprises a phosphorous screen for converting the amplified electron current to photon energy for providing the visual image.

7. A device as described in claim **1** in which the acoustic pattern has a frequency $f_a = (2\gamma/\lambda)$ where γ is the propagation velocity and λ is the wavelength of sound in the piezoelectric transducer.

8. A device as described in claim **2** in which the grid is maintained at a potential to repel low energy electrons and pass high energy electrons.

9. A device as described in claim **2** in which the microchannel plate electron multiplier has input and output electrodes at a potential for the required gain and the potential of the input electrode is several hundred volts higher than the grid potential.

10. A device as described in claim **9** in which the image converting means is a phosphorous screen maintained at a potential of approximately 5000 volts higher than the microchannel plate electron multiplier output electrode.

11. A device as described in claim **5** in which the charge pattern voltage, the biasing potential, the wavelength distribution of the radiation source, and the photocathode spectral response cooperate to provide nonlinear modulation of the electron current.

12. A device as described in claim **6** in which the conductivity of the photocathode is large enough to allow the photocathode current to remain at equilibrium with the electronic charge pattern and small enough to eliminate image quality degradation due to charge conduction.

13. A device as described in claim **12** in which the values of the volume resistivity and permititivity of the photocathode is such that the characteristic time constant of the photocathode is much larger than the applied acoustical period $1/f_a$ where f_a is the applied acoustical frequency.

14. A device as described in claim **1** which includes means for imaging the acoustic pattern on the piezoelectric transducer.

15. A device for converting an acoustic pattern into a visual image as described in claim **1** in which the source of electrons has a non-linear energy distribution.

16. A device for converting an acoustic pattern into a visual image as described in claim **15** in which the biasing potential causes the electronic charge pattern to modulate the electron current in a non-linear region.

17. A device for converting an acoustic input into a visual image, comprising a piezoelectric transducer, means for imaging the acoustic input on the piezoelectric transducer for providing an electronic charge pattern corresponding thereto, a photocathode having a non-linear electron energy distribution associated with the piezoelectric transducer, a radiation source for irradiating the photocathode to provide a source of electrons, a grid postitioned adjacent the photocathode and maintained at a potential to bias the electron current at a level of nonlinear electron energy distribution to provide an electron current modulated by the electronic charge pattern and having a spatial distribution of electron energies corresponding to the acoustic pattern, a microchannel plate electron multiplier positioned adjacent the grid for amplifying the modulated electron current, and a phosphorous screen positioned adjacent the microchannel plate electron multiplier for converting the electron current therefrom to photon energy for providing a visual image of the acoustic input.

18. A device for converting an acoustic input into a visual image as described in claim **17** in which the grid is maintained at a potential to provide an electron current modulated by the electronic charge pattern and having an average which varies in accordance with the acoustic input.

19. A device for converting an acoustic input into a spatial electron current, comprising a piezoelectric transducer for receiving the acoustic input and providing an electronic charge pattern corresponding thereto, a source of electrons associated with the piezoelectric transducer for providing an electron current, means for biasing the electron current at a potential to provide an electron current modulated by the electron charge pattern and having an average which varies in accordance with the acoustic input, and a microchannel plate electron multiplier for amplifying the modulated electron current.

20. A device as described in claim **2** in which the biasing means includes means for maintaining the grid at a potential below the potential of the source of electrons.

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