

Dec. 12, 1961

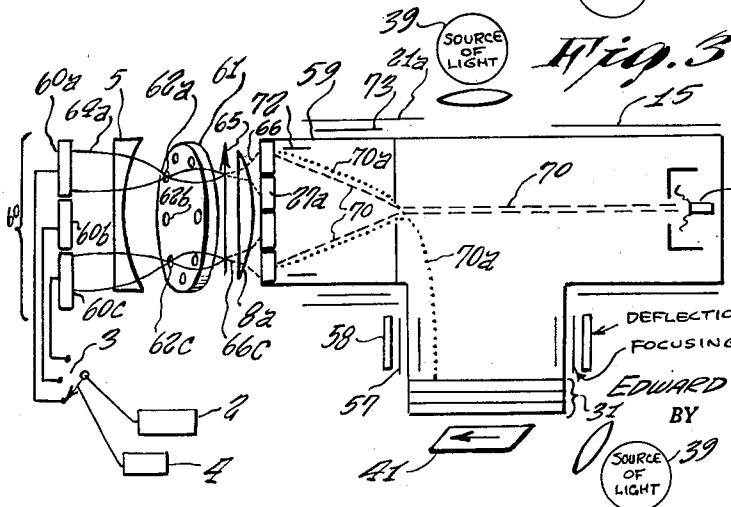
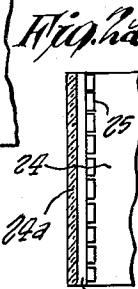
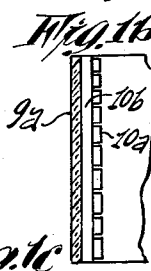
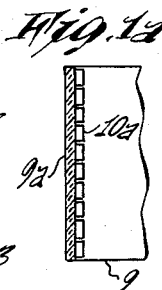
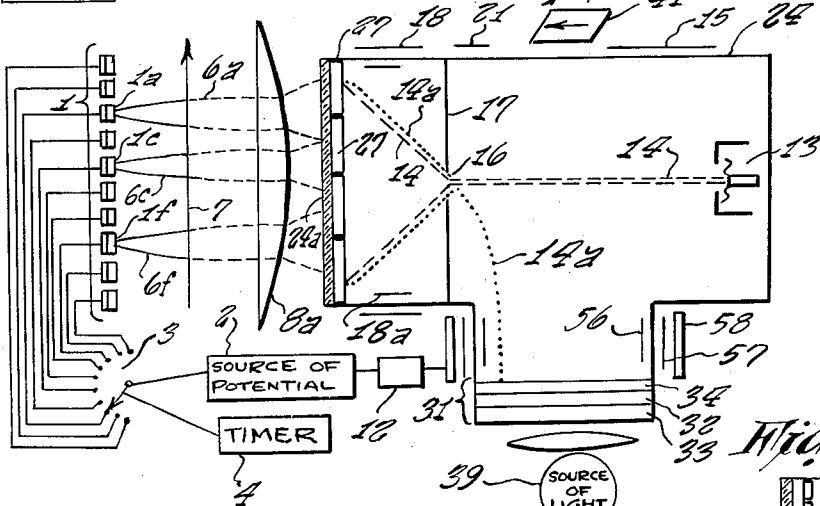
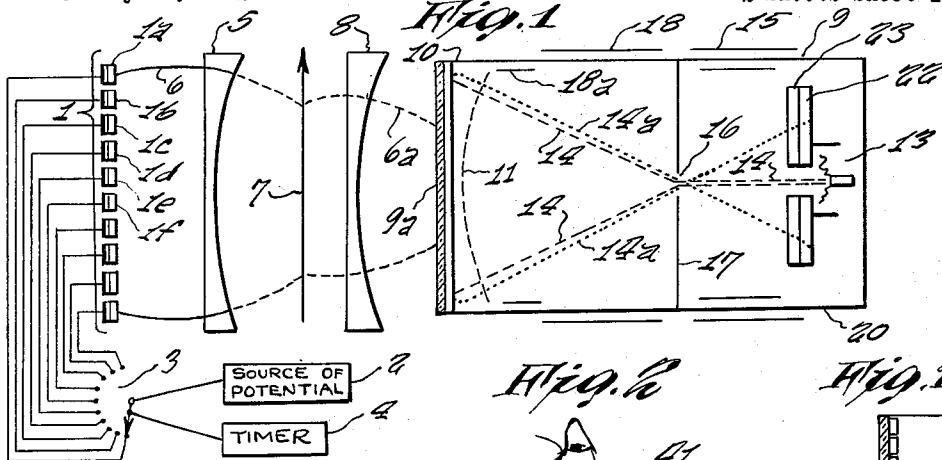
E. E. SHELDON

3,013,170

DEVICE FOR REPRODUCING ACOUSTIC IMAGES

Filed May 16, 1952

2 Sheets-Sheet 1



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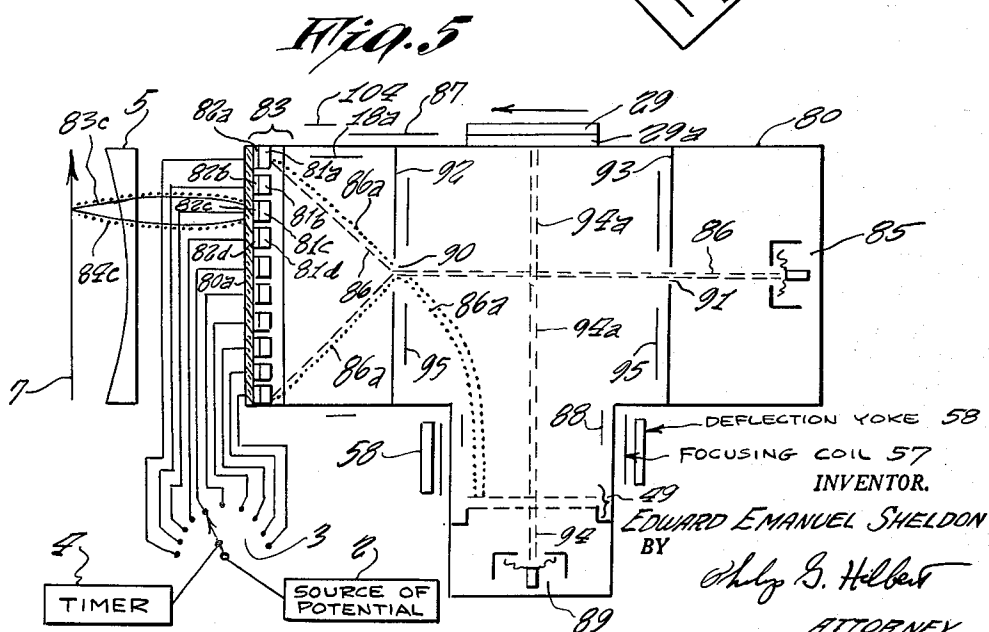
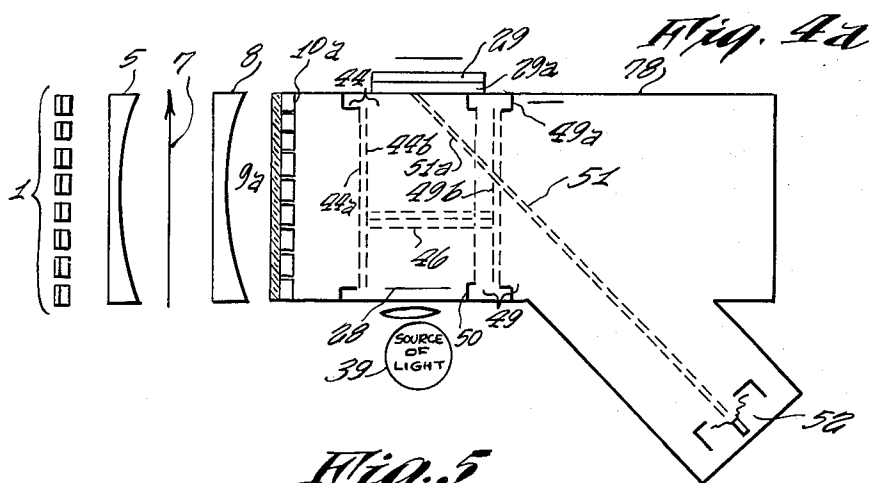
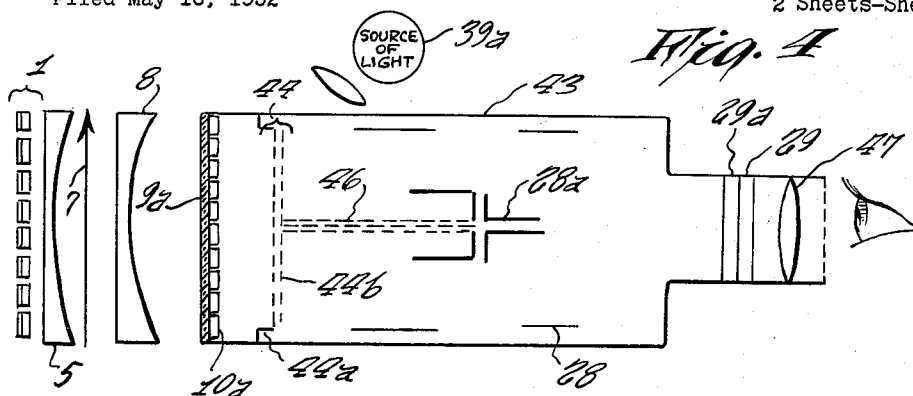
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DEVICE FOR REPRODUCING ACOUSTIC IMAGES

Filed May 16, 1952

2 Sheets-Sheet 2



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3,013,170

DEVICE FOR REPRODUCING ACOUSTIC IMAGES

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12 Claims. (Cl. 313-65)

This invention relates to a method and device for examination of various objects and living bodies by means of acoustic radiation and in particular, by means of supersonic waves. There are many devices known in the art for the purpose of supersonic examination; all of them, however, relate to producing signals indicating the information desired but not for producing two-dimensional or three-dimensional images of said information.

One primary object of this invention is to provide means for producing two supersonic images of the examined body, as distinguished from one-dimensional signals produced by devices of the prior art.

Another object of this invention is to provide a method and device for forming supersonic images of good detail and contrast. Another objective of the present invention is to provide means of storing supersonic images so that the supersonic exposure may be kept within limits of safety for patients and for living tissues in general. A few watts of acoustic energy per one square centimeter can be considered the maximum safe dose. It is obvious that it is of utmost importance to reduce the supersonic exposure as much as possible to be able to examine the patient without causing any injury. The best solution of this problem is the removal of supersonic radiation as soon as the supersonic image has been formed. This can be done only if the supersonic image can be stored for the desired period of time without maintaining the supersonic irradiation.

The purposes of my invention were accomplished by means of a novel system in which the supersonic beam is projected on the examined body. The reflected or transmitted supersonic beam is modulated by the examined body and carries, therefore, an invisible image thereof. The invisible supersonic image is projected onto a novel supersonic image sensitive tube. The supersonic image tube has a cathode for receiving image of material sensitive to supersonic energy, which in response to said energy, produces electrical charges and potentials having the pattern of said impinging supersonic beam. The pattern of charges and potentials is irradiated in the supersonic image tube by an electron beam. The electron beam is modulated by said pattern of potentials on the surface of the cathode. The returning electron beam carries, therefore, image information. The returning electron beam is intensified by acceleration and electron-optical diminution and is projected on the electron-reactive screen, which reproduces the invisible supersonic image for inspection or recording.

The invention will be better understood when taken in connection with the accompanying drawings.

In the drawings:

FIGURE 1 represents a diagrammatic cross-sectional view of supersonic image reproducing system.

FIGURE 1a represents a modification of supersonic sensitive cathode.

FIGURE 1b represents a modification of supersonic sensitive cathode.

FIGURE 1c represents another modification of supersonic sensitive cathode.

FIGURE 2 represents a modification of supersonic system in which a storage of the reproduced supersonic image is obtained.

FIGURE 3 represents a modification of supersonic

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image reproducing system for improving the definition of supersonic images.

FIGURE 4 represents a modification of the supersonic image system using in addition photoemissive means.

5 FIGURE 4a represents a modification of the embodiment of invention shown in FIGURE 4.

FIGURE 5 represents a modification of supersonic image reproducing system in which a reflected supersonic beam is used as a depicting radiation.

10 Reference now will be made to FIG. 1. The supersonic beam is produced by sender 1. The sender in this embodiment of invention consists of plurality of piezo-electric crystals 1a, 1b, 1c, 1d, 1e, 1f, etc., such as of quartz, lithium sulphate, barium titanate, dihydrogen potassium tartrate, known as DKT, ammonium dihydrogen tartrate, also known as ADT, or ethylene diamine tartrate, known as EDT.

In some cases, the sender may consist of one large piezo-electric crystal instead of plurality of crystals. It is to be understood that any piezo-electric material may be used for purposes of this invention. Piezo-electric crystals may be of various sizes and cuts. They should be selected to provide an equal and homogeneous output of supersonic energy, so that each crystal will produce the same quality and quantity of supersonic waves when excited by a high frequency source of potential. In case the crystals 1a, 1b, etc. do not have exactly the same output, they should be biased to equalize their output. To improve homogeneity of the supersonic field, it is better to use the crystals having a special cut, so-called Straubel cut. Further improvement of the homogeneity of the field may be obtained by using a mosaic of small crystals. Such mosaic can be made mechanically or by orientation of small piezo-electric crystals by means of supersonic waves. Each of the crystals in the sender 1 has a metallic backing plate to provide a connection to the source of electrical potential 2. The crystals are energized by said source of potential 2. The supersonic waves emitted from the energized crystals in the sender spread transversely to form a broad lobe of acoustic energy. Such a lobe obviously cannot be used for producing images with good definition and sharpness. Therefore, in my invention, I make use of acoustic lenses 5. The acoustic lenses may be of various forms and shapes, and it is to be understood that any device for focusing supersonic waves on the examined object 7 may be used for the purposes of my invention. One such modification are Fresnel plates, which are known in the art and, therefore, it is believed that they have not to be described in detail.

20 The diagnostic possibilities of supersonic waves reside in their characteristic properties of being reflected at the boundaries of two media having a different modulus of elasticity. Various tissues, fluid and air have different reflection, transmission and absorption values for supersonic waves. Therefore, the transmitted or reflected supersonic beam is modulated by the examined objects or tissues and carries information as to their pattern. A cavity can be demonstrated inside of the body regardless of its thickness. Also, a fluid containing cavity may be shown, if it is present inside of the examined tissues.

30 A very important indication for the use of supersonic waves is diagnosis of brain tumors, which impinge on ventricles in the brain and deform them. Ventricles of the brain contain normally cerebro-spinal fluid, which has different absorption, reflection and transmission properties for supersonic waves than the adjacent brain tissues. At the present time in order to visualize ventricles of the brain, it is necessary to inject into them air to provide contrast for X-rays. The use of my invention will eliminate this difficult and sometimes dangerous procedure as my device is able to visualize ventricles without injection of the air.

The supersonic sender 1 in this embodiment of invention operates continuously, which means that all crystals of the sender 1 are energized simultaneously. The broad supersonic beam 6 is focused on the examined object 7.

The supersonic beam 6a transmitted through the examined body 7 is now focused by means of an acoustic lens 8 on the novel supersonic image sensitive tube 9. The image tube 9 has a cathode of material responsive to supersonic waves, such as of quartz, barium titanate, piezo-electric ceramics, dihydrogen potassium tartrate, known as ADT, ammonium dihydrogen tartrate, also known as EDT, or ethylene diamine tartrate, known as EDT. The cathode 10 may be formed of one large crystal and is deposited within the tube on its wall 9a, as shown in FIG. 1. In such case, the layer 10 must have a high resistivity to prevent the lateral leakage of charges. Quartz will be suitable for this purpose. Better results will be obtained, however, by making the cathode 10 in the form of a mosaic 10a formed by plurality of small crystals and deposited on wall 9a of the tube 9, as shown in FIG. 1a. In some cases, it is preferable to deposit piezo-electric material on a dielectric base 10b, see FIG. 1b. In some cases, the piezo-electric cathode 10, whether of continuous type 10, or in the form of mosaic 10a, should be provided with a metallic backing 10c on the side facing the supersonic image, as shown in FIG. 1c.

The modulated returning electron beam 14a carrying the image impinges in this form of my invention on the fluorescent screen 22 made of long persistence phosphors such as of ZnS—Ag on ZnS: CdS: Cu or Al_2O_3 on ZnS: Ag or of single layer type such as, e.g., Zn(Mg)F₂: Mn or ZnScu(Ag); Cs₂P₂O₇: Dy or ZnS—CdS: Ag: Cu. The impingement of supersonic beam 6a on the cathode 10 causes so-called reciprocal piezo-electric effect. As a result, an electric charge or potential appears on the surface of the target 10 in the region which was struck by supersonic beam. Duration of this electrical charge of potential is very short. If the supersonic beam 6a has frequency in megacycles, the electric charge or potential will persist only for a few micro-seconds.

The electron gun 13 produces a broad electron beam 14. The electron beam 14 must obviously reach the target 10 at the time when electrical charge or potential on its surface is still present. The synchronization circuit is provided, therefore, to harmonize activation of the piezo-electric sender 1 with the activation of electron beam 14.

The uncovered surface of piezo-electric cathode 10 is irradiated by a broad beam 14 of electrons from the electron gun 13. The broad electron beam is focused by magnetic or electro-static fields 15 to a small diameter, so that it will pass through the aperture 16 in the light transparent diaphragm 17, such as of mica or glass. The electron beam 14, after passage through aperture 16, is enlarged by suitable magnetic or electro-static fields 18 to the size corresponding to the size of the area of the cathode irradiated by the supersonic beam. The electron beam 14, when approaching cathode 10 may have velocity of a few hundred volts. It is preferable, however, to use a slow electron beam. In such event, the electron beam 14 is decelerated in front of the cathode by an additional decelerating electrode 18a, which may be in the form of a ring or of a mesh screen. The electron beam approaching the layer 10 is modulated by the pattern of charges or potentials on its surface. The areas of a higher negative potential will reflect electrons more than areas having a lower potential acting as an electron mirror 11. The returning electron beam 14a is, therefore, modulated by the charge and potential image in the cathode 10 and carries the image of the examined body. The returning electron image 14a is now intensified by acceleration. This is accomplished by accelerating fields or electrodes,

which are well known in the art and, therefore, it is believed, that they do not have to be described in detail.

Further intensification of electron image may be obtained by its electron-optical diminution, which results in intensification proportional to the square power of linear decrease in size. The electron-optical demagnification is accomplished by magnetic or electrostatic fields and is well known in the art. The action of the electron beam 14 should be, preferably, intermittent and should last no longer than $\frac{1}{15}$ — $\frac{1}{30}$ second to avoid the flicker of reproduced image. After each irradiation period, the electron gun 13 may be inactivated for a very short time. Instead, the accelerating electrodes and the electron-optical lenses for electron-optical diminution of the returning electron image 14a are activated, now. The switching system for activating and inactivating electron gun 13 and the electrical fields described above may be operated by thyatron or ignitron controlled timer and is not shown in detail because it is well known in the art and will only complicate the drawings. It is obvious that my device may operate as a supersonic microscope by using electron-optical magnification.

The intensified electron image 14a is focused on the fluorescent screen 22, which has electron transparent light reflecting backing 23, such as of aluminum. The impingement of electron beam 14a on fluorescent screen 22 will reproduce the original invisible image as a fluorescent light image with a desired degree of intensification, which was the primary objective of this invention. The fluorescent screen 22 must have a very fine grain to be able to resolve the diminished electron image. ZnO phosphor is suitable for this purpose. Better results will be obtained by evaporated phosphors which have no grain structure and are, therefore, capable of reproducing images of high definition. Such phosphors were described in the article published in the Journal of the Optical Society, August, 1951, page 559. The fluorescent image can be viewed by the observer through the magnifying optical system, which will restore the image to the desired size without impairing its brightness. In some cases, the light reflecting layer may be omitted and image may then be viewed from the uncovered side of the fluorescent screen 22. The fluorescent screen 22 may be also deposited on the light transparent diaphragm 17 on the side facing the cathode 10.

I found that modulation of electron beam 14 by the charge or the potential image occurs in a very short time, such as a few micro-seconds. It is possible, therefore, to intensify the final fluorescent image in screen 22 by irradiating cathode 10 with electron beam 14 a few hundred or a few thousand times per second, instead of 15–30 times per second.

In some cases, the diaphragm 17 may be eliminated. In such event, the fluorescent screen 22 is protected from stray electrons of the electron beam 14 by lowering the potential of the screen 22, so that stray reflected electrons cannot penetrate through light reflecting layer 23.

A solution of the problem of viewing the final image in the straight axis instead of at an angle, is to place electron gun 13 in a special compartment, which is at the angle to the axis of the tube. This will make it possible to dispose the fluorescent screen 22 at the end of the image tube opposite to the cathode 10, which is at the other end of the tube. Therefore, the final image can now be viewed straight in the axis of the image tube.

A very important feature of my novel supersonic image reproducing tube is that it can be operated as a storage tube. This means that after the invisible image is formed in the cathode 10 as a pattern of electrical charges or of electrical potentials, supersonic radiation may be shut off and the image may be read for the desired time. This results in a great reduction of supersonic exposure of patients, which was one of the objectives of my invention. The operation of the image tube 9 as a storage tube is essentially the same as described above, except

that the reproducing screen 22 has storage properties, due to persistence of fluorescence.

Much longer storage effect can be obtained by using instead of the fluorescent screen, a screen which has the property of changing its color or becoming opacified under irradiation by the electron beam, as is shown in FIG. 2.

It is obvious that the above described supersonic image reproducing system may be used not only for the transmitted supersonic beam, but for reflected or scattered supersonic beam as well.

It is obvious that the supersonic sender 1, lenses, the examined object and the cathode end of the image tube 9 must be immersed in a liquid or other medium conducting for supersonic waves in order to avoid the loss of supersonic energy. A dielectric oil is a suitable medium for this purpose.

The supersonic sender 1 may also operate by pulses from its various component crystals instead of being energized simultaneously to produce a broad continuous beam, as explained above. As a result, successive, fine supersonic beams 6a, 6b, 6c, etc. are formed and each of them covers only one image point of the examined object 7. I found that piezo-electric crystals exhibit a marked lack of uniformity as to their reverse piezo-electric effect. It means that various areas of the same crystals produce different charges or potentials when impinged by the same supersonic beam. The "pulse" system of operation allows the equalization of the output of piezo-electric cathode 10, 10a, 10b or 10c. In this embodiment of my invention, I use, instead of the focusing supersonic lens 8, a defocusing lens 8a. In some cases, it is better to eliminate the lens 8a and instead, to dispose the image tube 24 at such distance, that one supersonic image point will irradiate all or part of cathode 10.

In this modification of my invention, the piezo-electric cathode 27 should be, preferably, of single crystal, or of a plurality of crystals assembled together; it should be also of material having a low lateral resistivity such as lithium sulphate or ADP.

In some cases, better results may be obtained by using a mosaic of piezo-electric crystals 25 provided with a common metallic backing plate 25a, as shown in FIG. 2a. The cathode 25 or 27 is deposited within the tube 24 on its wall 24a.

Each supersonic beam, e.g. beam 6c, impinging on the cathode 27 produces a charge or potential thereon which corresponds to one image point of the examined body. The supersonic beam 6c is defocused after passage through the examined body 7 in order to cover a large area of the cathode 27. In this way, the complications arising from non-homogeneous response of piezo-electric crystals are eliminated. The electron beam 14 is defocused in order to cover the area of the cathode 27, which was irradiated by supersonic beam 6c.

The returning modulated electron beam 14a represents one image point of the examined body. On its return, it is bent by suitable magnetic or electro-magnetic fields 21 and is focused by electrostatic or magnetic fields 57 to a fine point size. It is also intensified by acceleration and electron-optical diminution by suitable electrostatic or electromagnetic fields 56. Next it is deflected by the action of the deflection yoke 58 to be projected on the proper area of the opacifying screen 31. The impingement of electron beam 14a on said screen produces a pattern of discolorations or opacities therein which corresponds to various supersonic image points represented successively by the returning electron beam 14a. So far only the part of the image of the examined body was obtained which corresponds to supersonic beam 6c from the crystal 1c. Now, as the next sender, the crystal 1f is activated. The electron beam 14a is now synchronized with the supersonic beam 6f. In this way, the next fragment of the supersonic image is converted into visible image. This process continues until all supersonic senders have

been activated and the whole image of the examined object has been produced in the visible form as opacities image on the screen 31. The returning modulated electron beam 14a has to be suitably deflected, so that all image points are reproduced in their true space relationship. The synchronization circuit 12 between the sender 1 and the returning electron beam serves for this purpose.

The returning electron beam 14a may be further intensified before projecting it on the screen 31 by the secondary electron emission. In such case, the electron beam 14a is fed into a multi-stage multiplier. The multiplied electrons of said beam emerging from the multiplier are focused on the proper area of the screen 31.

In the preferred form of this invention, the activation of various crystals of the sender 1 does not occur in turn. After the sender 1a, the next sender to be activated is, instead of the sender 1b, the sender 1c. I found that in this way, the damage to the examined body by supersonic waves is considerably reduced. My explanation of this phenomenon is that by providing space between irradiated areas of living tissues, we accomplish a better dissipation of heat energy generated by the absorption of supersonic waves. In this way, the sensitive tissues of materials can better recover in the interval between supersonic energy pulses.

The opacifying screen 31 consists of a very thin layer 32 of material, which becomes discolored or opacified under electron bombardment. The thinner the layer 32, the better is the resolution of the reproduced image. A layer of 10^{-5} cm. thickness will be able to produce images having resolution of 2,000 lines. Suitable materials for the layer 32 are halides, such as chlorides, iodides, bromides or fluorides combined with alkalis, such as K, Na, Ca, Sr or Mg. Also AgCl or AgBr may be used for this purpose. The layer 32 may be of a single flat crystal or may have micro-crystalline structure or may be formed of a plurality of small crystals. The layer 32 is provided on either side with a light-transparent, conducting, very thin layer of a metal, such as tungsten. These metallic layers 33 and 34 can be deposited by evaporation or by sputtering and serve as electrodes for heating the layer 32. In some cases, these electrodes may be omitted. The composite screen 31 may be deposited on the inner side of the wall of the image tube 24 or may be mounted on a special supporting plate, such as of light-transparent mica or quartz. The electrodes 33 and 34 are provided with leads and receive the current from the source of electrical power in order to heat the layer 32 when the image has to be erased. Under bombardment by electron beam 14a, which has potential 10-20 K.V., an "opacities" image is produced in the screen 31, which has the pattern of the original supersonic image. This opacities image remains stored in the screen 31 for a long time, because it is produced by a formation of color centers in the lattice of the crystals forming the layer 32. A strong source of light 39 irradiates the composite screen 31 through the window in the image tube. This light is modulated by the pattern of the opacities present in the layer 32. Therefore, the transmitted light image will have the pattern of said opacities, which means it will reproduce the pattern of the original supersonic image. This transmitted light image can be projected on a viewing screen 41 and can be examined thereon for a long time. In this way, in spite of stopping the supersonic exposure, the supersonic image will persist in the screen 31 for a long time. Therefore, the supersonic image can be examined for a desired period of time without exposing the patient to supersonic radiation, which was one of the primary objects of this invention.

Instead of using a transmitted light, the reflected light may be used for this purpose as well.

It is obvious that the source of light 39 for transillumination of the "opacities" image may also be disposed on the side of the tube opposite to the opacifying

screen 31. In such case, the projection screen 41 will be disposed on the same side as the opacifying screen 31.

After the supersonic image has been examined, it can be erased by heating the layer 32. The heating is accomplished by passing a strong electrical current through the metallic electrodes 33 and 34. The potential of the electrode 34 is positive in relation to the potential of the electrode 33 in order to provide electrical field across the layer 32. Under the influence of said electrical field, the opacities move in the direction of the anode and disappear. The erasing of the opacities image may also be accomplished by scanning the layer 32 with a strong electron beam from the electron gun 13. Whereas an electron beam of 0.5 ma. is sufficient for producing an opacities image, an electron beam of 10 to 100 ma. will be necessary for erasing this image. The heating and the electron bombardment of the layer 32 can be combined if speedy erasing is necessary.

The layer 32 produces in response to a bombardment by the electron beam 14a not only opacities, but also changes of its refraction power in relation to the light. These changes of refraction can be used for modulation of the source of light. It is possible, therefore, to reproduce this "refraction" image as a visible image by using the optical system of Schlieren. Schlieren's system is well known in the art and does not have to be described in detail.

It is obvious that the opacifying screen 31 may be used as well in the image tube 9 instead of the fluorescent screen 22. It is also evident that the fluorescent screen 22 may be used instead of the opacifying screen 31 in the supersonic image tube 24. My device may also serve as a supersonic microscope by using electron-optical magnification of the electron beam having the pattern of supersonic image.

In order to reduce the number of supersonic senders, I made the modification in which each sender crystal 1a, 1b, etc. has one part of the cathode 27 assigned to it. Crystal 1a produces a fragment of the supersonic image in the area A of the cathode 27, crystal 1b produces another fragment of the supersonic image in the area B of the cathode 27.

The electron beam 14 is defocused to cover the area A or B at one irradiation. The modulated returned electron beam 14a will store the information which it carries in the opacifying screen 31. The electron beam 14 must have simple deflecting means to make it scan areas A, B, etc. of the cathode 27 in succession. Also deflecting means must be provided for the returning electron beam 14a to make it impinge on the areas on the screen 31 corresponding to irradiated areas A, B, etc. of the cathode. After all areas of the cathode 27 have been irradiated and all corresponding fragments of the image have been assembled in the screen 31, the final image will be projected on the viewing screen 41, as was explained above.

It is obvious that the supersonic sender 1, lenses, the examined object 7 and the cathode end of the image tube 24 must be immersed in a liquid or other medium conducting for supersonic waves in order to avoid the loss of supersonic energy. A dielectric oil is a suitable medium for this purpose.

Another modification of my invention is shown in FIG. 3 and is suitable for producing images of fine definition. In this embodiment of my invention, the supersonic sender 60 is simplified because we don't need any longer a large number of sender crystals to provide supersonic irradiation of all points of the examined area. The reduction of the number of crystal senders is made possible by the use of a rotating filter 61. This filter consists of a disc or a drum provided with multiple uniform apertures 62a, 62b, 62c, etc. The filter 61 rotates at a high speed which depends on resolution of the image to be reproduced. The number of apertures 62 in the filter also controls the resolution of the image. The supersonic beam 64a from the crystal 60a, which is energized first, is transmitted in succession through small apertures 62a,

62b, 62c and etc. in the filter 61, and is reduced thereby each time to a fine beam having the diameter of said apertures. The rest of the supersonic beam 64a is stopped by the filter 61. It is very important that there should be no reflection of the stopped supersonic beam from the filter 61, because reflected supersonic waves will interfere with the operation of the sender 60. Therefore, the rotating filter 61 should be made of material having good absorption properties for supersonic waves. Rubber is suitable for this purpose. The beam 64a may be projected on the examined body 65 or may be first focused by the lens 5. The acoustic lens 5 is movable to provide focusing of the supersonic beam for various distances required. Instead of the lens 5, the apertures 62a, 62b, 62c etc. in the filter 61 may be filled with small acoustic lenses. The use of rotating filter 61 makes it possible to have only one sender crystal for the examination. Such crystal has to be large enough to irradiate the examined body. Large crystals are not suitable for producing high frequency supersonic waves. In medical examination, the frequency of supersonic waves should be in megacycles to provide a good definition of the image as the wave-length of supersonic waves depends on their frequency. It is better, therefore, to use a small number of piezo-electric crystals and to energize them sequentially by means of commutator 3, as was explained above. In any event, the use of rotating filter 61 represents an important improvement of the supersonic system because of simplification of the sender 60.

The transmitted supersonic beam 66 represents an invisible image point of the examined body 65. The beam 66 impinges now on the novel supersonic sensitive image tube 59. The supersonic beam 66 carrying the image information is allowed to spread over large area of the supersonic sensitive cathode 25 or 27. This can be obtained by the use of a divergent lens 8a or by positioning of the supersonic pick-up tube 59 at a proper distance from the examined body. As a result, the supersonic beam 66 strikes a large area of the cathode 27a. The importance of this modification resides in the fact that the reverse piezo-electric effect is not uniform over the surface of the same crystal as was explained above. The cathode 27a consists of a few or a plurality of crystals having a low lateral resistivity, such as used in cathode 27, which are assembled together. The electron gun 68 produces the electron beam 70. The electron beam 70 is defocused by the action of magnetic or electrostatic fields 73 to cover a large part of or all of the cathode 27a. It is decelerated in front of the cathode 27a by the decelerating cathode 72, which may be in the form of a ring electrode or in the form of a mesh screen.

The electron beam 70 approaches the cathode with velocity close to zero volts. It is modulated by the charge or potential present on the cathode 27a due to the action of supersonic beam 66. Now the modulated electron beam 70a returns in the direction of the electron gun 68.

The returning electron beam 70a carries information corresponding to one image point of the examined body. It is now bent by the action of magnetic field 21a and is focused to a fine point size by the action of magnetic or electrostatic fields 57. Next, it is deflected by the action of deflection yoke 58 and is projected on the opacifying screen 31, as was explained above. In this way, all image points can be stored and assembled in the screen 31 in their proper space relation. Synchronizing circuits serve to harmonize the action of the sender 60 and of the rotating disc 61 with the electron beam 70. Synchronizing circuits are well known in the art and it is believed, therefore, that they do not have to be described in detail. The opacities image formed in the screen may be projected by the transmitted light or by the reflected light from the light source 39 on the projection screen 41 for inspection or recording. It is evident that instead of the opacifying screen 31, the fluorescent screen 22 made of persistent phosphors described above, may be used as well.

It is obvious that the sender 60 with the rotating disc 61 may also be used with the image tube 24.

It is obvious that this invention may also serve as a supersonic microscope by using electron-optical enlargement of the electron beam having the pattern of super-sonic image.

The use of the opacifying screen has the drawback that such screen provides images of good definition but of very poor contrast. The use of a fluorescent screen allows much better contrast of images, but it is not possible to use it in many applications, because the phosphors do not have good storage properties. As was explained above, the reduction of supersonic exposure is urgently needed in medical examinations and may be accomplished best by storage of images. This problem is solved in embodiment of my invention shown in FIG. 4. The tube 43 has supersonic sensitive cathode 10a described above which is deposited within the tube on its wall. In close spacing, such as a few microns, to the cathode 10a, there is mounted a fine mesh screen 44a of a conducting material. On said mesh screen, there is deposited a photo-emissive layer 44b in such a manner as not to obstruct the openings in the mesh. The pattern of the electrical charges on the layer 10a can be considered as a pattern of various potentials or electrical fields. These potentials will modulate the emission of photoelectrons from the photoemissive layer 44b, although they are behind said layer. The layer 44b is irradiated by a source of light 39a and produces a strong beam of photoelectrons. The emission of photoelectrons from the layer 44b depends on electrical fields in its proximity. The more negative the charges in the cathode 10a, the more suppressed will be the emission of photoelectrons from the layer 44b. In this way, the photoelectron beam will be modulated by the charges in the cathode 10a, which have the pattern of the original invisible supersonic image. The photoelectron image 46 is accelerated and focused by the electromagnetic or electrostatic fields 28 on the fluorescent screen 29 having an electron transparent conducting backing layer 29a, such as of aluminum. Instead of the fluorescent screen 29, the opacifying screen 31 may be used as well. The focusing and accelerating fields are not indicated in detail as they are well known in the art and will only serve to complicate the drawings. Sometimes it is better to demagnify the photoelectron image electron-optically before projecting it on said target. This can be done by the use of electron lenses 28a.

The photoemissive screen 44 may be also deposited on the piezo-electric cathode 10a. The potentials formed by the supersonic image in the cathode 10a will leak in the areas adjacent to the conducting screen 44a, but between the wires of the screen, the potential pattern will persist and will control emission of photoelectrons from the photoemissive layer 44b. It may be added that photoemissive perforated screen 44 may also be used in the image tube 24 illustrated in FIG. 2 or in the image tube 59 illustrated in FIG. 3. In such case, the photo-electron beam 46 modulated by the supersonic image represents only one image point of said supersonic image. The photo-electron beam 46 in this modification of the invention can also be intensified by feeding it into a multiplier prior to reconvert it into a visible image in a fluorescent or opacifying screen.

Another modification of my invention is shown in FIG. 4a. The supersonic image is converted in the image tube 78 into a photo-electron image 46, as was explained above and illustrated in FIG. 4.

The photoelectron image 46 is accelerated and focused by the electromagnetic or electrostatic fields 28 on the perforated storage target 49. The focusing and accelerating fields are not indicated in detail as they are well known in the art and will only serve to complicate the drawings. Sometimes, it is better to demagnify the photoelectron image electron-optically before projecting it on said target.

This can be done by the use of electron lenses. The perforated storage target 49 is of dielectric material, such as of quartz, precipitated silica, CaF_2 , BaF_2 , mica or glass. The perforated storage target 49 can be mounted in the tube by means of metallic rings or the storage layer may be deposited on a fine mesh screen 49a, so that openings in said screen are not obstructed. The storing dielectric layer 49b should face the photoelectron beam.

The photoelectron image is focused on the target 49 with velocity causing secondary emission from the target at the ratio greater than unity (S greater than 1). The secondary electrons emitted from the dielectric target are drawn away by the adjacent conducting mesh screen 50 or by a collector electrode. In this way, the photoelectron image is deposited as a positive charge image on the target. It is obvious that photoelectron image 46 can also be focused on the target 49 with velocity, at which secondary electron emission is smaller than unity (S smaller than 1). The resulting charge image will then be a negative one. In such case, the mesh screen 50 may be omitted.

In the second phase of operation, the light source 39, the focusing fields 28 and the collecting electrode 50 are inactivated. Instead, the electron gun 52 is made active now. A strong broad beam of electrons 51 is emitted from the activated electron gun 52 or from a source of photoelectrons, such as photoemissive surface irradiated by light. This beam 51 has to pass through the perforated dielectric target 49. The passage of electrons 51 is modulated by the charge image deposited on said dielectric target by the action of the photoelectron beam 46, which has the pattern of invisible supersonic image. Therefore, the beam of electrons 51a, which passes through the dielectric target 49 will have imprinted on it the pattern of the original invisible supersonic image. The transmitted electron beam 51a is of a much greater intensity than the original supersonic image. Therefore, by converting said transmitted electron beam 51a into a visible image in the fluorescent screen 29, a marked intensification of the original supersonic image is obtained. The fluorescent screen 29 has an electron transparent, light reflecting backing layer 29a, such as of aluminum, to prevent back-scattering of light. Instead of fluorescent screen, other electron reactive surfaces may be used, such as the opacifying screen 31 described above, photographic films, electrolytic papers or electrographic plates. The transmitted electron beam 51a before its reproduction into visible image may also be intensified by acceleration and electron-optical demagnification, as was explained above.

The electron beam 51 may also be of a ribbon type, or of a scanning type. In such case, deflection yoke 58 must be provided to assemble all image points in their proper space relation.

The storage target 49 may store electrical charges for a long period of time, ranging from a few seconds to a few minutes, depending on the dielectric material used. During the storage time, the supersonic beam may be shut off, as it is no longer necessary to maintain the presence of the supersonic image. This results in a marked reduction of supersonic exposure, which was one of the primary objectives of my invention. The stored charge image on the target may be removed by irradiating it with a photoelectron beam from the photoemissive layer 44b with a velocity at which it will produce the charges of the opposite sign in relation to the stored charges.

It is evident that the tube 78 may use the cathodes 25 or 27 instead of the cathode 10 or 10a. In such case, the tube 78 will reproduce image points successively instead of the whole image simultaneously.

Another modification of my invention for the purpose of providing the storage of supersonic images and at the same time preserving the contrast of the reproduced images, is shown in FIG. 5. In this embodiment of invention, the function of supersonic sender and image tube are

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performed by one and the same tube 80. The novel sender-image tube has cathode 83, which is made of plurality of piezo-electric crystals 81a, 81b, 81c, etc., such as of quartz, barium titanate, ADP, EDP, lithium sulphate or others. Each crystal is deposited on a conducting layer 82a, 82b, 82c, etc. such as of metal. The cathode 83, which may also be defined as a target, is deposited inside of the tube 80 on its wall 80a. Each of said crystals is connected separately to the source of potential 2. They are energized sequentially by the action of commutator 3, as was explained above. The commutator is controlled by the timer 4. The supersonic beam 83c produced by crystal 81c is focused by the acoustic lens 5 on the examined body 7. As was explained above, supersonic waves are reflected at the boundary of two different materials. Therefore, reflected supersonic waves are modulated by the examined body 7 and carry its invisible image. The reflected supersonic beam 84c returns to the crystal sender 81c. The sender 83 is now disconnected from the source of potential 2 by the action of commutator 3. The returning supersonic beam 84c impinging on the crystal 81c produces a pattern of potentials or charges in it due to reverse piezo-electric effect. This pattern of charges or potentials is of a very short duration, such as a few micro-seconds. The electron gun 85 is activated now and produces the electron beam 86. The electron beam 86 must arrive to the crystal 81c at the time when the pattern of charges is present thereon. This method of operation has the following advantage. The spurious reflections of supersonic waves may be eliminated by my device. It means if we know that the investigated area is of a certain distance from the sender, we may calculate the time necessary for supersonic waves to return from this area and will energize the electron beam 86 according to this time. In such case, all supersonic waves reflected from objects at different planes than the investigated one will have no effect on the electron beam 86 and, therefore, will not interfere with image.

The sender preferably should not be energized until all supersonic waves reflected by the most distant plane of the examined object passed away, in order to avoid their interference with the new supersonic waves sent by the next crystal.

It is obvious that the tube 80 may be used for "continuous" method of operation where the total supersonic image is produced simultaneously, as well as for "pulse method," in which separate image points are produced sequentially and reassembled into a total image. In the "continuous" operation, the supersonic beam 84 carrying the total image of the examined body, impinges on the cathode 83 and produces therein a pattern of electric charges or potentials corresponding to the total supersonic image. This electrical pattern is irradiated by the broad electron beam 86 from the electron gun 85. The electron beam may be defocused at its defining aperture or it may be defocused by the action of magnetic or electrostatic fields 104 after passage through the apertures 90 and 91 in the electrodes 92 and 93. The broad electron beam 86 is decelerated in front of the cathode 83 by the action of decelerating electrode 13a, which may be in the form of a ring electrode or of a mesh screen. The electron beam 86, after being modulated by the charge pattern on the free surface of the cathode 83, returns. The returning beam 86a is bent by the action of the magnetic or electromagnetic fields 87 and is projected on the perforated storage target 49, which was described above. Further intensification of the returning electron beam 86a may be obtained by acceleration and electron-optical diminution. The electron-optical demagnification is accomplished by means of magnetic or electro-static fields and is well known in the art. The action of the electron gun 85 must be synchronized with the action of the supersonic sender 83, so that the electron beam 86 will arrive to the cathode 83 at the time when the supersonically induced charge image is present

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thereon. The action of electron gun 85 should preferably be intermittent, so that the returning electron beam 86a can be accelerated and projected on the storage target 49 without interference from the incoming electron beam 86. In this operation of my device, the crystals of the cathode 83 must be of high resistivity, so that the charges produced on its surface by the supersonic image will not suffer from lateral leakage. Quartz will be a suitable material in such case. The returning broad electron beam 86a is modulated by said charge or potential on the cathode 83 and stores this information in the storage target 49. Then begins the reading phase of the operation, in which the supersonic sender, the electron gun 85 and the magnetic fields 87 are inactivated. In this phase of operation, the electron gun 89 is activated and produces a broad electron beam 94. The passage of the electron beam 94 through the perforated storage target 49 depends on the charges stored therein, as was explained above. As a result, the transmitted electron beam 94a is modulated by the stored charge image and, therefore, has the pattern of the original supersonic image. The transmitted electron beam 94a may be intensified by accelerating fields 95, which may be in the form of coating on the electrodes 92 and 93. The intensified electron beam is projected on the fluorescent screen 29 to reproduce an invisible image. It is obvious that instead of the fluorescent screen 29, the opacifying screen 31 may be used as well.

In some cases, instead of the broad electron beam 86, a scanning electron beam may be used. In such event, the deflecting circuits are necessary to provide the scanning motion for said electron beam across the target 83. Another deflection yoke 58 will serve to deflect the returning electron beam in order to assemble all image points in the storage target 49 in their proper space relation. Also, the electron beam 94 in some applications may preferably be of the scanning type.

This novel sender-image tube 80 may, obviously, also be used for "image point" method of operation. In such case, the sender 83 operates sequentially by energizing crystals separately one after another.

In this modification of my invention, the piezo-electric crystals 81a, 81b, etc. should preferably have a low lateral resistivity, as was explained above, and should be continuous to each other, as shown in FIGS. 2 and 3. The returning modulated electron beam 86a, obviously represents now only one image point. The returning electron beam 68a is focused to a fine point size by the action of electrostatic or magnetic fields 57; next, it is deflected by the deflection yoke 58 and is projected thereby on the proper area of the target 49. This process is repeated in successive irradiations until all image points have been reproduced and assembled on the storage target 49 in form of electrical charges. The rest of the operation is then the same as was described above.

It should be understood that the above described supersonic image reproducing system may be used not only for the reflected supersonic beam, but for transmitted or scattered supersonic beam as well.

It is obvious that the supersonic sender, lenses, the examined body and the cathode end of the image tube must be immersed in a liquid or other medium conducting for supersonic waves in order to avoid the loss of supersonic energy. A dielectric oil is a suitable medium for this purpose.

It is to be understood that the above described supersonic-image reproducing system may be used not only for medical examinations but for industrial testing as well.

My invention may also be used for supersonic image microscopy. The enlargement of the supersonic image of the examined body may be attained by electron-optical fields in any of the image tubes described above. The embodiments of my invention illustrated in FIGS. 3 and 4 are especially suitable for this purpose.

As the various possible embodiments might be made of the above invention and as various changes might be

made in the embodiment above set forth, it is to be understood that all matter herein set forth or shown in the accompanying drawings, is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. A vacuum tube having in combination a screen comprising means sensitive to supersonic radiation having plurality of piezo-electric elements, said means being mounted in said tube for receiving supersonic radiation pattern and for converting said radiation into an electrical pattern, said screen being furthermore supported by the wall of said tube, means for producing a broad beam of electrons, said beam being modulated by said electrical pattern, and means for receiving said modulated broad electron beam.

2. A device as defined in claim 1 which comprises a screen for receiving said modulated electrons.

3. A vacuum tube having in combination a screen comprising means sensitive to supersonic radiation, said means being mounted in said tube for receiving supersonic radiation pattern and for converting said radiation into an electrical pattern, said screen being furthermore supported by the wall of said tube, means for producing a broad beam of electrons, means for decelerating said beam, said decelerated beam being modulated by said electrical pattern, and means for receiving said modulated broad electron beam.

4. A device as defined in claim 3, in which said supersonic radiation sensitive means comprise piezoelectric material.

5. A vacuum tube having in combination a screen comprising means sensitive to supersonic radiation, said means being mounted in said tube for receiving supersonic radiation pattern and for converting said radiation into an electrical pattern, said screen being supported by the wall of said tube, said tube furthermore comprising means for producing a broad beam of electrons to be modulated by said electrical pattern, said means for producing said electron beam being spaced apart from said screen, and means for receiving said modulated electron beam.

6. A device as defined in claim 5, in which said supersonic radiation sensitive means comprise piezoelectric material.

7. A device as defined in claim 5, in which said supersonic radiation sensitive means comprise a plurality of supersonic radiation sensitive elements.

8. A vacuum tube having in combination a screen comprising means sensitive to supersonic radiation, said means being mounted in said tube for receiving a supersonic

radiation pattern and for converting said pattern into an electrical pattern, said screen furthermore being supported by the wall of said tube, means for producing a broad beam of electrons, said beam being modulated by said electrical pattern, and means for receiving said modulated broad electron beam and reproducing said electrical pattern as a visible image, said reproducing means being within said tube and comprising a light impervious layer and a luminescent layer.

9. A device as defined in claim 8, in which said means for producing said broad electron beam are spaced apart from said supersonic radiation sensitive means.

10. A vacuum tube having in combination a screen comprising means sensitive to supersonic radiation, said means being mounted in said tube for receiving said radiation pattern and converting said radiation into an electrical pattern and having at least one surface uncovered, said screen being furthermore supported by the wall of said tube, means for producing a beam of electrons, said means producing a beam of electrons being spaced apart from said screen, means for decelerating said electron beam, means for irradiating with said electron beam said supersonic radiation sensitive means, said beam being modulated by said electrical pattern and reflected by said electrical pattern, and means for receiving said reflected modulated electron beam.

11. A device as defined in claim 10, in which said means sensitive to supersonic radiation comprise a plurality of piezo-electric elements.

12. A device as defined in claim 11, in which said means sensitive to supersonic radiation are disposed with their front surface and back surface within said tube and in which said means sensitive to supersonic radiation comprise piezo-electric material.

References Cited in the file of this patent

UNITED STATES PATENTS

2,164,125	Sokoloff	June 27, 1939
2,270,232	Rosenthal	Jan. 20, 1942
2,306,272	Levy	Dec. 22, 1942
2,453,509	Dimmick	Nov. 9, 1948
2,528,726	Rines	Nov. 7, 1950
2,541,374	Morton	Feb. 13, 1951
2,555,423	Sheldon	June 5, 1951

OTHER REFERENCES

Boyle: "Diffraction Reflection . . . Sound Intensity," Canadian Jour. of Research, vol. 3, No. 6, December 1930.