United States Patent [19]

Boll

[11] **3,766,311**

[45] **Oct. 16, 1973**

[54] **SENSORY SUBSTITUTION SYSTEM**

[76] Inventor: **Harry Joseph Boll,** 289 River Bend Rd., Berkeley Heights, N.J. 07922

[22] Filed: **Apr. 26, 1972**

[21] Appl. No.: **247,567**

[52] **U.S. Cl.** ..... **178/6,** 3/1, 35/35 A, 340/407, 178/DIG. 32

[51] **Int. Cl.** **H04n 7/18**

[58] **Field of Search** ..... 178/DIG. 32, 6, 6.8; 340/407; 35/35 A; 3/1

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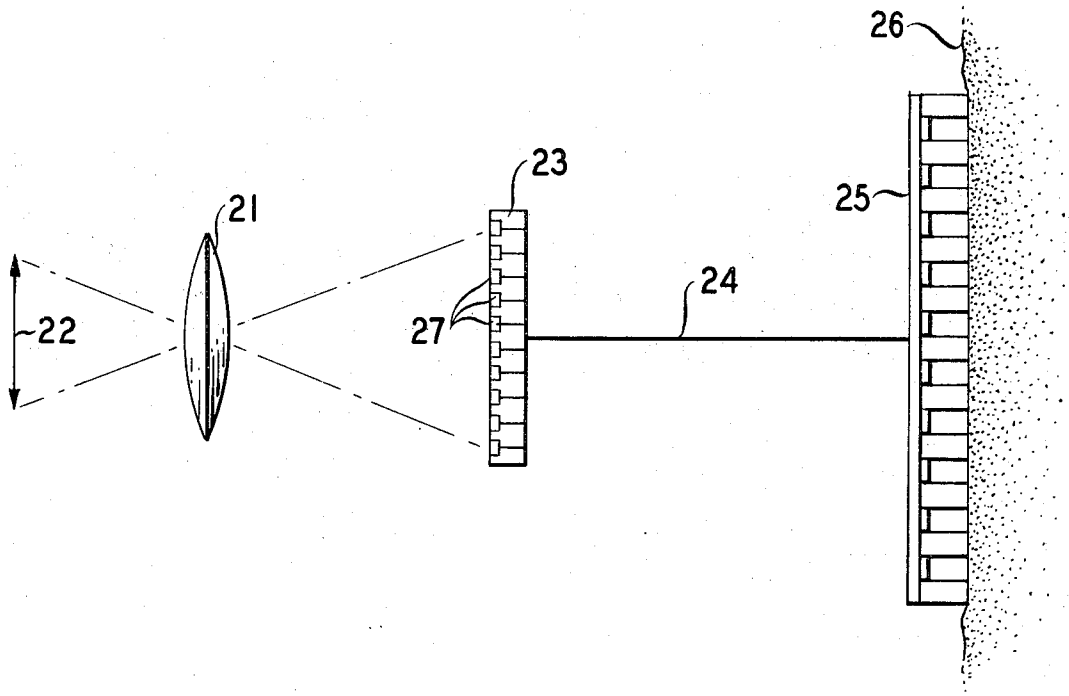
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Primary Examiner—Robert L. Richardson
Attorney—George Wesley Houseweart

[57] **ABSTRACT**

There is disclosed apparatus for converting electrically-coded information into selective, intelligible, localized cooling of a receptive heat-producing medium, e.g., a human body. In combination with a vidicon for producing the electrically-coded information, the apparatus enables a blind person to perceive images and motion in the form of distinguishable localized cooling of the skin. In combination wth a microphone, amplifier, and filters for producing the electrically-coded information, the apparatus enables a deaf person to perceive auditory information also in the form of distinguishable localized cooling of the skin. Advantageously, the selective, localized cooling of the skin is achieved by covering a portion of the body with an apertured insulating medium and selectively gating body-produced heat therethrough. In presently preferred embodiments, the selective gating is achieved by a vibrating disc driven by a vibrating reed which, in turn, is driven by a piezoelectric element.

28 Claims, 15 Drawing Figures



4 Sheets-Sheet 1

FIG. 1

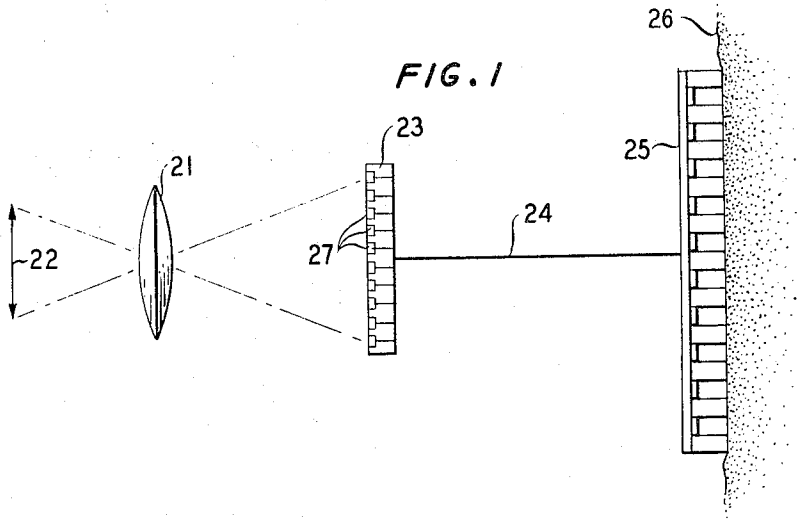


FIG. 2

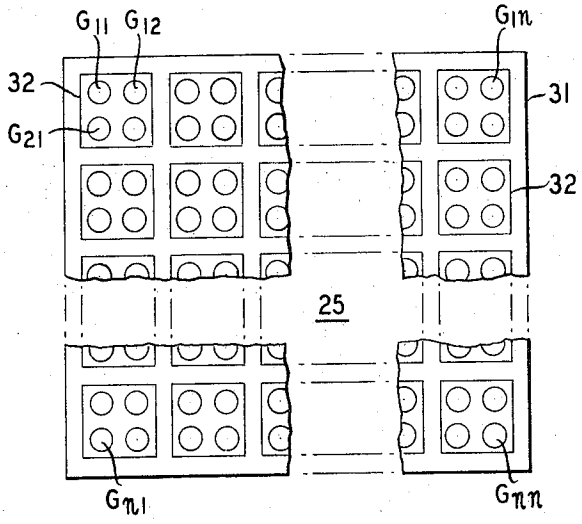


FIG. 3

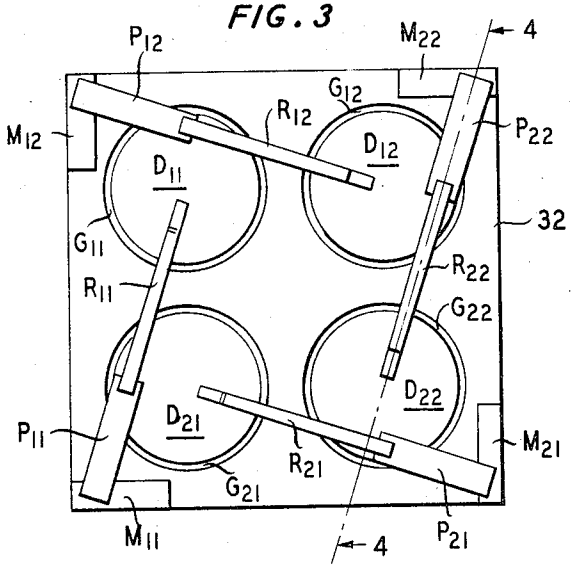


FIG. 4

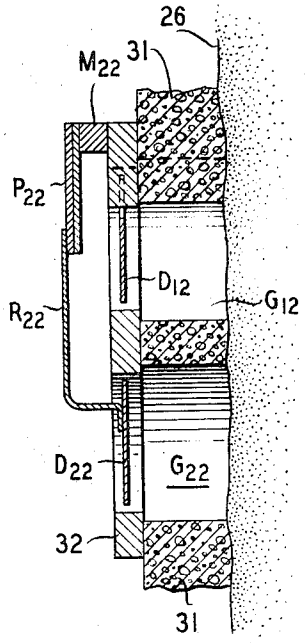


FIG. 5

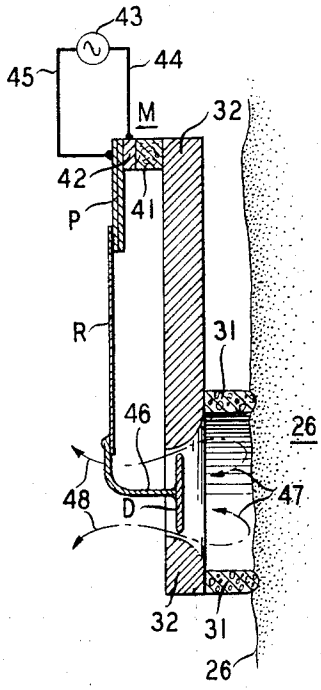


FIG. 6

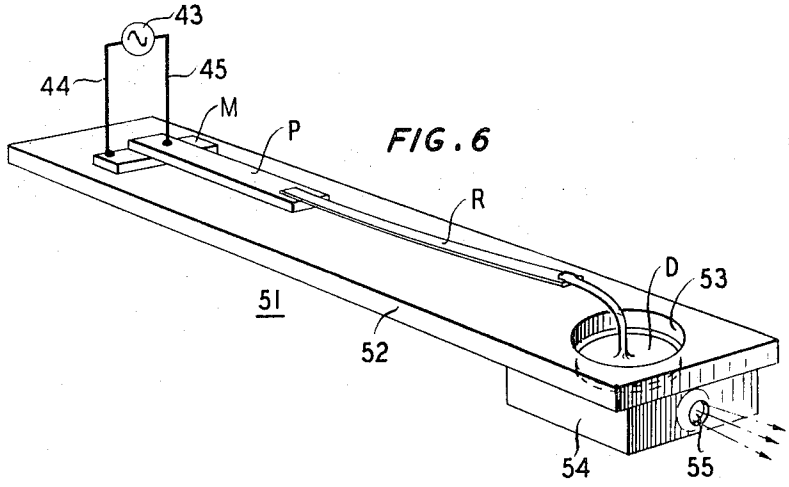


FIG. 7

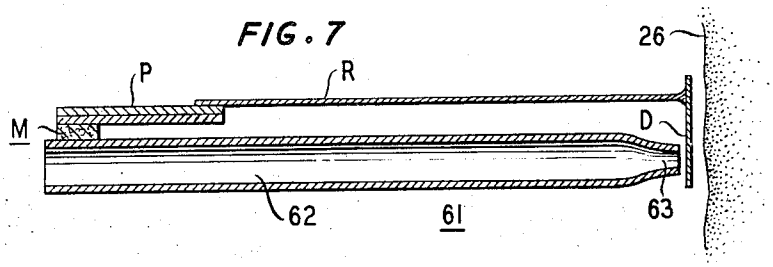


FIG. 8

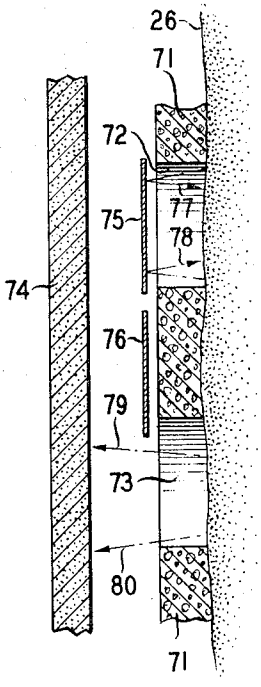


FIG. 9

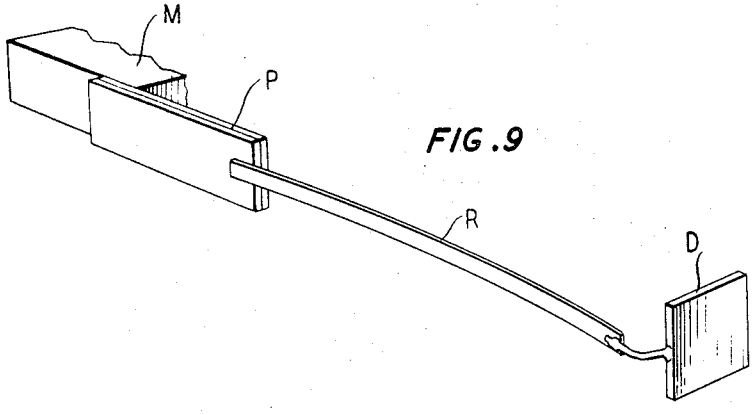


FIG. 10

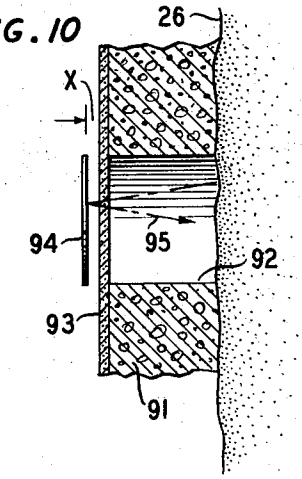


FIG. 11

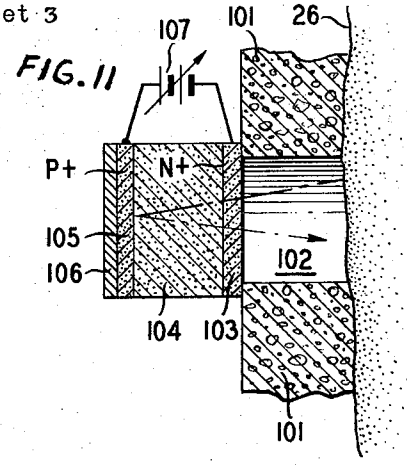


FIG. 12

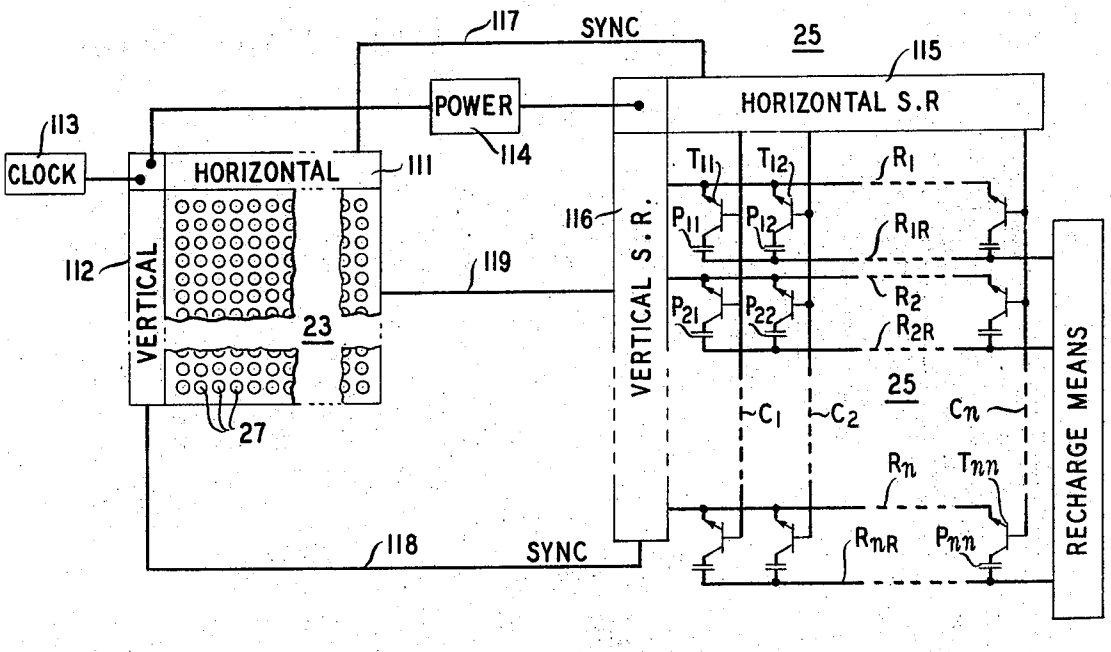


FIG. 13

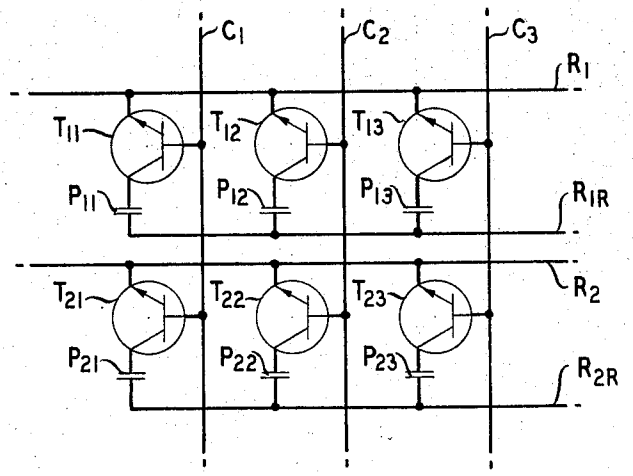


FIG. 14

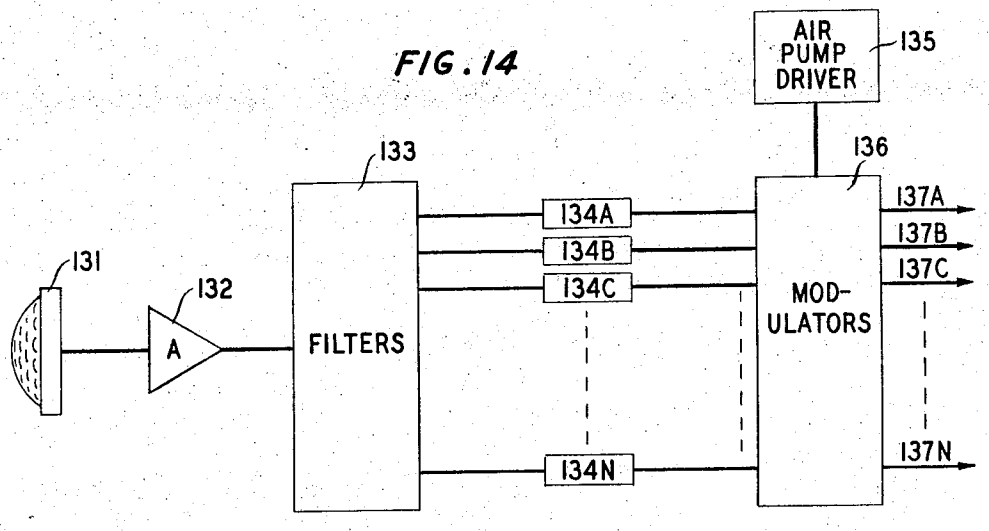
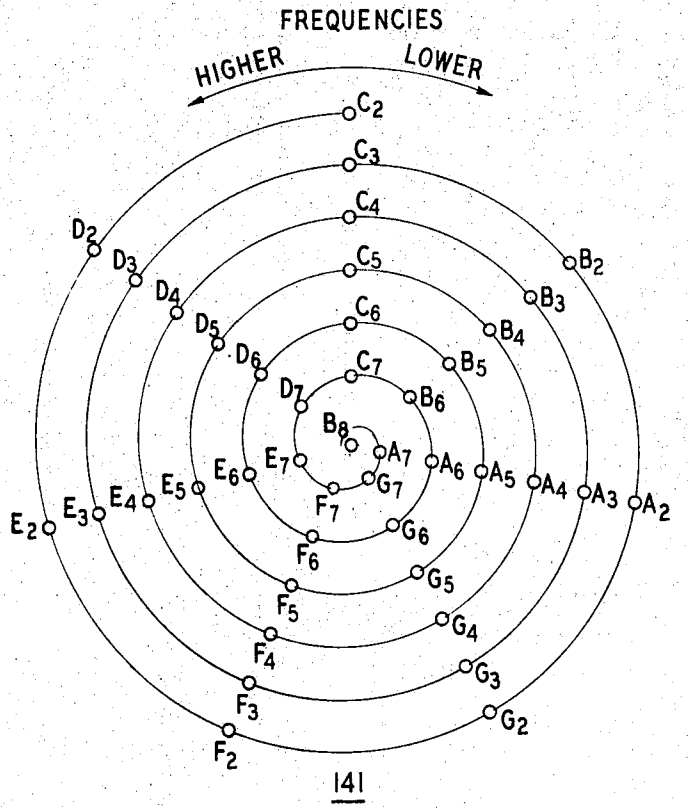

AIR PUMP DRIVER
135
136
133
131
132
A
FILTERS
134A
134B
134C
134N
MOD-ULATORS
137A
137B
137C
137N

FIG. 15


FREQUENCIES
HIGHER
LOWER
C2
C3
C4
C5
C6
C7
D2
D3
D4
D5
D6
D7
B2
B3
B4
B5
B6
B8
A7
A6
A5
A4
A3
A2
E2
E3
E4
E5
E6
E7
G7
F7
G6
F6
G5
F5
G4
F4
G3
F3
G2
F2
141

SENSORY SUBSTITUTION SYSTEM

BACKGROUND OF THE INVENTION

This invention relates to sensory substitution systems such as vision-substitution systems and auditory-substitution systems; and, more particularly, to such systems employing selective, intelligible, localized stimulation of the skin for enabling sensory reception of information.

While there is little work reported in auditory-substitution systems for the deaf, a great variety of reading aids and other vision-substitution systems for the blind have been proposed. Early systems involved striking the skin with selected ones of an array of electro-magnetically-driven plungers for imparting electrically-coded vision information tactually to the skin. While operative for fixed-position, reading aid uses, such systems are insufficiently sensitive for viewing objects and landscapes, and, additionally, are impractically cumbersome and power-consuming for portable uses.

A more modern tactile system, the basics of which are disclosed in U.S. Pat. No. 3,229,387, issued Jan. 18, 1966, to J. G. Linvill, substitutes piezo-electrically-driven vibrating reeds for imparting selective tactile stimulation to the skin. While offering improvements for reading aid uses, the Linvill apparatus is believed useful only on the hands and feet because those portions of the skin are more sensitive to tactile stimulation than are the hairy parts of the body. This limitation is a problem because the feet and hands should be free for walking and grasping if the vision-substitution system is to enable a blind person to approach the functional capability of a sighted person.

In general, a basic problem with tactile stimulation systems is that the skin must be struck with varying intensities of force for imparting information thereto. This force requirement implies an unnecessarily high consumption of power which, in turn, implies unnecessarily large batteries to be carried with the apparatus. Another serious problem with tactile systems is that the sense of touch tends to deaden, i.e., become less sensitive, with repeated use. This implies that with use, ever greater amounts of power consumption are required for retaining the same capability for imparting information to the skin.

Another major type of vision-substitution system employs localized electrical stimulation of the skin for imparting information thereto. A modern form of such systems, disclosed in U.S. Pat. No. 3,562,408, issued Feb. 6, 1971, to C. C. Collins, employs complex apparatus for converting image information into constant current bursts of electric shock pulses which are applied to the skin through electrodes in engagement with the skin. While this and other types of electrical stimulation systems offer lower power operation than heretofore known tactile systems, electrical stimulation systems suffer from a variety of other disadvantageous characteristics such as: a person's innate fear of electrical shock; continued discomfort because electrical shock remains an unnatural and uncomfortable sensation; variation in the skin's sensitivity to electrical shock from spot-to-spot along the skin; variation in sensitivity to electrical shock due to condition of the skin, e.g., moisture; deadening of skin to a given amount of electrical shock after repeated shocking; and the basic danger of painful or even fatal shocking possible if system safeguards fail.

SUMMARY OF THE INVENTION

In view of the above-mentioned and other shortcomings of known sensory substitution systems, a primary object of this invention is light-weight, portable, low-power apparatus for imparting information to the skin of a person via a localized, comfortable and natural sensation and which can be worn or carried on the person without substantial impairment in his mobility.

In contradistinction to known sensory substitution systems, apparatus in accordance with this invention involves a departure from the concept of merely directing a force, be it mechanical or electrical, at the body for imparting information thereto. More specifically, in accordance with this invention and in contradistinction to known sensory substitution systems, energy generated and given off by the human body is selectively controlled, i.e., gated, using power from an external source. Thus, energy generated by the human body is the principal energy factor in apparatus in accordance with this invention, while energy from an external source, e.g., a battery, is only a secondary energy factor. Because of this aspect of the invention, low external power consumption is enabled.

More specifically now, it is known that every living person generates power in the form of thermal energy, i.e., heat, from metabolizing food. In accordance with a preferred form of this invention, some of this heat is temporarily conserved by covering a portion of the skin with an apertured thermally insulating layer to provide an array of body-heated quiescent air spaces adjacent that portion of the skin. Selective agitation of these air spaces in response to information signals produces concomitant selective cooling of localized portions of the skin adjacent those air spaces. Such selective cooling of the skin is distinguishable by the skin-nervous system-brain complex two-dimensionally with temporal integrating.

In a presently preferred form of the invention, agitation of each quiescent air space is accomplished by forced convection resulting from a piezoelectrically-driven vibrating reed and disc.

In another form of the invention, pressurized air is selectively gated through an orifice into each quiescent air space by a piezoelectrically-driven reed and valve.

Another described form of selective cooling involves a piezoelectrically-driven vibrating reed and reflective shutter for selectively gating radiant heat from the quiescent air spaces.

BRIEF DESCRIPTION OF THE DRAWING

It is believed the aforementioned and other objects, features, and advantages of the invention and the invention in general will be better understood from the following more detailed description taken in conjunction with the drawing in which:

FIG. 1 is a schematic, block diagram of a basic form of apparatus for use as a vision-substitution system in accordance with this invention;

FIG. 2 is a simplified, partly schematic plan view of apparatus including a matrix of devices for enabling selective, localized cooling of the skin in accordance with this invention;

FIG. 3 is a more detailed plan view of a portion of the apparatus of FIG. 2;

FIG. 4 is a cross-sectional view, taken along line 4—4 of the apparatus of FIG. 3;

FIG. 5 is a cross-sectional view of a presently-preferred form of miniature pump for selectively cooling, by forced convection, a portion of the skin in response to signal information in accordance with this invention;

FIGS. 6 and 7 are schematic plan views of alternative forms of miniature pumps for use with this invention;

FIG. 8 is a somewhat schematic cross-sectional view of apparatus for enabling selective cooling of the skin by selectively inhibiting in accordance with this invention the rate of heat lost by radiation from the skin;

FIG. 9 depicts, from a different cross-sectional view, a portion of the apparatus of FIG. 8 in more detail;

FIGS. 10 and 11 depict, in somewhat schematic cross-sectional view, alternative forms of apparatus for enabling selective cooling by selective inhibition of radiation loss in accordance with this invention;

FIG. 12 is a schematic, partly block, circuit diagram of advantageous time-division multiplexing apparatus for routing electrically-coded visual-information signals from an electronic camera to the selective cooling apparatus in accordance with this invention;

FIG. 13 is an enlarged view of a portion of the apparatus of FIG. 12;

FIG. 14 is a schematic, block circuit diagram of a basic form of apparatus for use as an auditory-substitution system in accordance with this invention; and

FIG. 15 is a schematic plan view of an advantageous array of selective cooling devices for use in an auditory-substitution system in accordance with this invention.

It will be appreciated that certain reference numerals have been repeated in successive figures to indicate corresponding elements where considered appropriate and helpful in understanding the invention.

DETAILED DESCRIPTION

With more specific reference now to the drawing, FIG. 1 illustrates in schematic, somewhat block diagram form a basic vision-substitution system of the general type suitable for use and employed in various embodiments of the present invention. As shown, the system includes a lens 21 for projecting an image of an object 22 to be perceived onto an electronic camera 23 that converts the varying light intensity across the image into electrical signals representative thereof. These electrical signals are conveyed via one or a plurality of conductors 24 to a transducer unit 25 contiguous with or near to some portion 26 of a person's skin. In accordance with this invention, transducer unit 25 provides selective, localized stimulation of the skin in accordance with the electrical signals.

More specifically now, to realize suitable sensitivity, low power, and portability, camera 23 advantageously is a solid state vidicon having an array of solid state photosensors 27, each being operative separately to produce electrical signals corresponding uniquely to the intensity of light incident thereon. For example, although sensitivity is not as great as desired, the model OPT-5 vidicon presently commercially available from Plessey Electronics, Ltd., can be used in operative embodiments of this invention in normally illuminated environments. The Plessey device is a self-scanned vidicon having 100 photosensors in a 10 by 10 array and, as is desirable for this invention, is small enough for mounting on an ordinary frame for eyeglasses.

Transducer unit 25 advantageously includes a plurality of individual transducers in an array in one-to-one correspondence with the photosensors, each transducer being operative to selectively stimulate a very small portion of the skin 26 thereadjacent with intensity of stimulation related to the intensity of light incident upon the corresponding photosensor. As will be discussed in more detail below, each photosensor can be connected to its corresponding transducer by a separate conduction path or paths (as taught, for example, in the aforementioned Linvill patent); or vidicon 23 and transducer unit 24 can include suitable multiplexing apparatus so that the units can be interconnected by a single conduction path over which all necessary information signals may flow. A multiplex technique with a single signal path is preferred, as it facilitates processing of signal information, if desired, for achieving, among other things, DC level control, automatic gain control, clipping of signals, and/or signal inversion to enable darker objects to provide greater skin stimulation than lighter objects.

As was mentioned above, in a broad aspect this invention is characterized, in contradistinction to known sensory substitution systems, by apparatus for selectively gating energy (in the form of body heat) away from the skin, as opposed to all heretofore known systems, which are characterized by application of energy (mechanical or electrical) to the body. As such, an important part of this invention lies in the transducer unit 25.

In FIG. 2 there is shown a simplified schematic plan view of a typical transducer unit 25 including a matrix of transducers adapted for selectively stimulating a small portion of the skin in accordance with this invention. FIGS. 3 and 4 are plan and cross-sectional views, respectively, showing a portion of the apparatus of FIG. 2 in greater detail. As shown, transducer unit 25 includes an apertured thermally insulating medium 31, e.g., a plastic foam such as polyurethane, which advantageously is thin, light-weight, and resilient so that it is comfortable and conforms to body contours when worn, for example, contiguous with a part of the chest or upper abdomen as part of a vest. Chest or upper abdomen mounting of the transducer unit is considered preferable inasmuch as it is believed such can be made less obtrusive and less restrictive upon normal human activities. For example, appendage mounting interferes with appendage use; back mounting may be uncomfortable when sitting. In an early embodiment of this invention, the vidicon was mounted in the crown of a hat; and the transducer unit was suspended from the front brim of the hat such that selective stimulation, i.e., cooling, of the user's forehead was enabled. While entirely operative for the purposes of this invention, such mounting is believed unnecessarily obtrusive and could make the user feel self-conscious.

In more detail now, a plurality of apertured rigid plates 32 are mounted on medium 31 with apertures G_{ij} therein registered in one-to-one correspondence with the apertures in medium 31. As shown in FIGS. 3 and 4, with each aperture G_{ij} there is associated a disc D_{ij} connected to one end of a reed R_{ij}, the other end of which is connected to a piezoelectric element P_{ij}. Piezoelectric element P_{ij} is mounted on plate 32 preferably by a simple, electrically insulating mounting block

M_{ij} which includes electrical terminals (not shown in FIGS. 2–4) for coupling electrical signals to the piezoelectric element.

As is known, application of a periodic voltage to a piezoelectric element causes it to vibrate synchronously with the voltage, provided the frequency of the voltage is not too great. Frequencies of the order of about 50 to 200 cycles per second at voltages of the order of about 50 to 150 volts are common. If the vibrating frequency of any element P_{ij} is at or near the resonant frequency of the vibrating reed R_{ij} attached thereto, and if the Q of reed R_{ij} is reasonably high (for example, about 20), only a relatively small signal power (for example, about one milliwatt) need be applied to element P_{ij}, e.g., length 0.5 inch, thickness 0.02 inch, width 0.07 inch, to produce a relatively large vibratory displacement (for example, about 2 millimeters of disc D_{ij} attached to a reed R_{ij} of length of about one inch. As is explained in greater detail below, vibration of disc D_{ij} produces agitation of and at least partial exchange of the body-heated air in the insulated air space under disc D_{ij}. This air agitation and exchange produces concomitant cooling of that part of the skin which is under aperture G_{ij} and disc D_{ij}.

Advantageously, iaccordance with this invention, the electrical signal amplitude is proportional to the incident light intensity; and the disc displacement is proportional to the signal amplitude. Accordingly, the degree of cooling is proportional to the light intensity, i.e., the brighter the light incident upon any given photosensor, the greater the cooling of the skin under the corresponding disc D_{ij}. For example, if there is a bright object in the center of the visual field, the central sensors of vidicon **23** send signals to the corresponding piezoelectric elements P_{ij} in the center of transducer unit **25** and localized cooling of the skin thereunder relative to other parts of the skin under the transducer unit is experienced. If the bright object moves across the visual field, the localized cooling also moves in a corresponding way across the "field" under the transducer unit. Through a learning process, the brain learns to construct mental images of the actual scene being transmitted, just as the brain of a sighted person constructs mental images due to varying light intensities incident upon the retina of the eye.

Of course, it will be understood that in FIGS. 2–4, plates **32** are shown each including four apertures and cooling elements only for illustration. Obviously, each such plate can include one or any plurality of apertures and cooling elements, as desired. Four are illustrated, as four have been found convenient while not rendering unit **25** unduly stiff. And, of course, plates **32** are described as "rigid" because of the need to maintain constant the relative placement of the mounting blocks, discs, and apertures.

Inasmuch as the selective localized cooling is considered broadly new with this invention, there will now be described in detail a plurality of means and types of means for accomplishing the cooling by forced convection. Many details unessential for explaining modes of operation have been omitted for clarity and simplicity.

More specifically now, in FIG. **5** there is depicted, with most of the unessential detail omitted, a miniature pump of the type previously depicted in FIGS. 3 and 4. As seen, the pump includes rigid plate **32**, mounting block M, piezoelectric element P, reed R, and disc D. For simplicity, subscripts "*i*" and "*j*" indicating row and column have been omitted. Mounting block M includes an electrical insulating portion **41** and a conductive portion **42**, the conductive portion for making electrical contact to element P mounted thereon. For example, block M may be a copper-clad fiberglass board, with one side of element P being affixed thereto by soldering, welding, or conductive adhesive such as conductive epoxy. A source **43** of periodic voltage is shown connected to opposite sides of element P by conductors **44** and **45**.

In operation, application of the periodic voltage to opposite sides of piezoelectric element P causes it to vibrate in flexure, i.e., such that the end attached to reed R moves up and down in FIG. **5**. Piezoelectric devices and their characteristics are well known in the art, a particular example being lead-zirconate-titanate (PZT) being available commercially from the Vernitron Corporation, Cleveland, Ohio, under the trade name "bimorph." Vibrating reeds likewise are well-known, thin pieces of brass or phosphor-bronze sheet being one example. In fabrication, one end of reed R is affixed, by nonconductive epoxy adhesive, for example, to the free end of element P but electrically insulated from the voltage applied to element P. Disc D is connected to the othe end of reed R by, for example, an aluminum wire **46** of diameter about 0.020 inches, by weld, solder, or adhesive.

As element P moves up and down in flexure, its displacement is magnified by the length and Q of reed R, provided the movement of element P is at or near the resonant frequency of reed R. Thus, as Q is increased, the power required to drive disc D decreases; but also, as Q is increased, so is the settling time increased. Settling time is the time required for disc oscillations to damp out after cessation of driving voltage and must be kept reasonably small, e.g., of the order of 0.1 second, so as not to blur successive information signals more than desired. Apparatus with a net Q of about 20 have been used successfully. Net Q must be considered, since air damping at disc D retards vibration of reed R.

In operation, with no signal applied to element P, disc D comes to rest; and air in the space defined by the aperture in medium **31**, plate **32**, and disc D is quiescent and is warmed by body heat, since cooling by normal convection and radiation is interrupted. As disc D is made to vibrate in accordance with an information signal from source **43**, fresh air is thrust into the quiescent air space through the gap between the disc and the aperture wall in plate **32** on the upstroke (indicated by arrows **47**); and, on the downstroke, air from the quiescent space is ejected (indicated by arrows **48**) into the surrounding ambient. As a result of this agitation and exchange of air, there is a cooling sensation of the skin thereunder when the disc is vibrating; and the degree of cooling is essentially proportional to the amplitude of vibration, at a given frequency.

FIG. **6** depicts an alternate type of pump **51** for operation with cooling by forced convection. As in the apparatus of FIG. **5**, pump **51** includes a rigid mounting plate **52**, mounting block M, piezoelectric element P, reed R, and disc D connected to reed R by a thin wire. Plate **52** includes an aperture **53** through which disc D vibrates. Under aperture **53** is a closed cylinder **54** (shown as a square for illustration) having a small opening **55**, preferably flared for operation as a nozzle. Typical dimensions are: 1 inch by 2 inches by 0.010 inch for plate **52**; 0.25 to 0.5 inch diameter for aperture

53; 0.05 to 0.10 inch diameter for opening **55.** Disc D is of diameter typically 0.05 inch smaller than the diameter of aperture **53** to allow sufficient clearance for unimpeded vibration.

When at rest, the plane of the disc D is positioned outside and below, for example, about 0.01 inch below, the lower surface of the aperture **53** in plate **52.** In operation, air agitation and exchange occur when disc D of pump **51** is made to vibrate up and down inside cylinder **54** and aperture **53** with a vibration amplitude, for example, of about 0.080 inches peak-to-peak. At the beginning of a downstroke, with the disc inside aperture **53,** the disc pushes air down aperture **53,** through cylinder **54,** and out opening **55** onto the skin. After the disc reaches the midpoint of its downstroke, the disc no longer drives air; but, because of the momentum of the air in the cylinder and in opening **55,** the air continues flowing out opening **55** in the same direction. This air flow continues on the upstroke as well, until the disc re-enters the aperture. Then there is a short period of reverse flow until the beginning of the next downstroke. The result is a net flow of air out of opening **55.**

In accordance with this invention, the air flow from opening **55** is directed into a quiescent air space in a medium such as medium **31** of FIG. **2**; and, as described there, the degree of cooling is proportional to disc vibration amplitude, which, in turn, is proportional to signal amplitude from the corresponding photosensor. Although the pump of FIG. **5** is preferred for use in this invention, pump **51** of FIG. **6** offers certain interesting features. With the nozzle **55** directed as shown in FIG. **6,** reed R and element P extend perpendicular to the skin, a feature which could enable closer packing of pumps, but which also tends to make the transducer unit somewhat thick and bulky. Alternatively, of course, nozzle **55** could as well be placed in any other face of cylinder **54** so as to direct air to the skin while the pumps are aligned with body contour. At this point it is to be noted that pumps as shown in FIG. **6** were used in the hat-brim embodiment mentioned above.

With reference now to FIG. **7,** there is shown still another type of apparatus for cooling by forced convection in accordance with this invention. As shown, apparatus **61** includes an air duct **62** on which is mounted, with mounting block M, a piezoelectric element P, reed R, and disc D. In operation, pressurized air from a conventional blower is made available in duct **62** and is directed onto the skin **26** in a quiescent air space through a nozzle **63** when disc D is made to vibrate away from the nozzle opening. While such apparatus is not preferred due to the need for a conventional bulky and power-consuming blower and due to the need for means to convey air to each duct **62,** the apparatus **61** is operative and can be used in accordance with this invention, if desired.

At this point, it will be appreciated that a principal function of medium **31** in FIGS. **2–4** is to maintain a substantially uniform, small spacing of the miniature pumps from the skin, **26,** and that another principal function of medium **31** is to inhibit loss of body heat. Accordingly, medium **31** ideally should have a thermal conductivity as low as possible, and, at worst, not substantially larger than that of the quiescent air in the apertures. Inasmuch as the thermal conductivity of quiescent air is about 5×10^{-5} calories per centimeter-second-degree Centigrade, the thermal conductivity of layer **31** should be no larger than about 5×10^{-4} calories per centimeter-second-degree Centigrade. In this context, it should be appreciated that medium **31** can be a composite, layered medium and may, in fact, include a metallic sheet of very high thermal conductivity spaced from the skin by pegs, for example, and having a dead, i.e., quiescent, air layer trapped between itself and the skin for inhibiting heat loss therethrough. However, an apertured solid medium of low thermal conductivity is preferred, as the apertured solid tends to reduce smearing of the cooling sensations between adjacent pumps.

Of course, at this point, it should be appreciated also that the inner faces (next to the skin) of the discs, D_{ij}, should be of high radiation reflectance to reduce spurious heat loss by radiation through the quiescent air spaces in the apertures thereunder.

With reference now to FIG. **8,** there is shown in somewhat schematic cross-section apparatus for enabling selective cooling in accordance with this invention by selectively inhibiting the rate of body heat lost by radiation from the skin. As shown, the apparatus of FIG. **8** includes an apertured, thermal insulating medium **71,** like medium **31** of FIG. **2,** only two apertures, **72** and **73,** being illustrated for simplicity and clarity. Over and spaced from medium **71** is a continuous i.e., non-apertured, radiation-absorbing medium **74** which is maintained at a temperature below that of skin **26** by any of a variety of means, not shown, which will be apparent to those in the art. Between medium **71** and layer **74** are a plurality of radiation-reflecting shutters **75** and **76,** e.g., aluminum or other metallic foil, separate ones being associated with and registered with each aperture in medium **71.**

In a quiescent state, illustrated by shutter **75** completely covering aperture **72,** the reflecting characteristic of the shutter returns radiated heat to the skin **26,** indicated by arrows **77** and **78,** and there is little heat loss from skin **26.** When a shutter is open, i.e., aperture uncovered as illustrated by shutter **76** displaced from aperture **73,** radiation escapes to absorbing layer **74,** indicated by arrows **79** and **80;** and a net flow of heat away from skin **26** into absorbing layer **74** is realized. Rate of heat loss is selectively controllable by controlling the percentage opening of the shutter.

A number of ways for controlling the shutters of FIG. **8** will be apparent to those in the art. One way, illustrated in FIG. **9,** employs a piezoelectric element P and vibrating reed R, like those previously disclosed with respect to FIGS. **2–7,** for driving each shutter, e.g., **75,** in a vibratory mode with respect to aperture **73** by applying periodic signals to element P. When reed R vibrates, the shutter periodically is moved away from its aperture (totally or partially, depending on vibration amplitude), thereby allowing a controllable amount of radiation loss and concomitant cooling.

Another type of apparatus for selectively inhibiting the rate of body heat lost by radiation in accordance with this invention is shown in somewhat schematic cross-section in FIG. **10.** As shown, the apparatus includes an apertured thermally insulating medium **91,** only one aperture, **92,** being shown for convenience. Over medium **91** is a very thin (for example, about 100–1000 Angstroms) radiation-absorbing material **93** (for example, a carbon film) spaced close to a highly reflecting material **94,** e.g., aluminum. As seen, material **94** need be disposed only over the aperture and is

spaced from the surface of layer **93** thereover by a distance X. As is known from the principles applicable to electromagnetic energy, if X is small compared to the wavelength (typically about 10 microns) of the radiant energy (indicated by broken-line arrow **95**) from the skin, then the absorbing layer traps very little energy because the electric field is small near the reflecting boundary **94.** But, if X approaches one-fourth the wavelength of the radiation, then the electric field in layer **93** is high and the radiant energy is absorbed and a cooling sensation is experienced under aperture **92.** Thus, by moving either reflecting material **94** or absorbing material **93,** selective cooling can be achieved, provided layer **93** is maintained at a constant temperature by any of a variety of means not shown. A variety of means for holding and moving reflecting material **94** as requried in this embodiment will be apparent to those in the art. For example, material **94** can be a thin film, e.g., aluminum or gold, disposed on one surface of an electrostrictive material, such as a piezoelectric material. In this case, a voltage applied to the piezoelectric material causes physical shrinkage thereof, with concomitant movement of film **94** away from layer **93.** Further details will be apparent.

Still another type of apparatus for selectively inhibiting the rate of body heat lost by radiation in accordance with this invention is shown in somewhat schematic cross-section in FIG. **11.** As in previous embodiments, the apparatus includes an apertured thermal insulating layer **101,** only one aperture **102** being shown for convenience. Over aperture **102** is a three-layer semiconductor, including, for example, a thin N^+-type layer **103,** e.g., 0.5 microns thick, adjacent the aperture, a thicker intrinsic layer **104,** e.g., 100 microns thick, thereover, and a thin P^+-type layer **105,** e.g., 0.5 microns thick, over layer **104.** Outer layer **105** is covered with a highly reflecting material **106.** A source **107** of variable voltage has negative and positive terminals connected, respectively, to N^+-type layer **103** and P^+-type layer **105.**

In operation, with little voltage applied, radiant energy can pass relatively freely through the semiconductor without significant absorption, since there are relatively few free charge carriers in intrinsic layer **104.** Reflecting material **106** returns the radiant energy to the skin **26** with little heat loss. If, however, an electron-hole plasma is generated in the intrinsic semiconductor **104** by increasing source **107** so as to forward bias the diode and inject free charge carriers, the plasma absorbs the radiation and a cooling sensation under aperture **102** is experienced, provided the temperature of the semiconductor is maintained constant by any of a variety of means not shown. It will be appreciated, of course, that N^+-type and P^+-type layers **103** and **105** must be very thin so that they do not significantly absorb the radiant energy, and, in particular, must be sufficiently thin that the number of free charge carriers therein is much less than the number of free charge carriers which can be injected in the selectively formed plasma.

With reference now to FIGS. **12** and **13,** there is shown a schematic, partly block, circuit diagram of advantageous time-division multiplexing apparatus for routing electrically-coded visual information signals from an array of photosensors to corresponding elements of the transducer unit for selective cooling in accordance with this invention. As in FIG. **1,** the system includes a solid state vidicon **23** including a matrix of photosensors **27** which are scanned in time sequence by means of a horizontal shift register **111** and a vertical shift register **112,** which, in turn, are driven by a source **113** of clock signals. The aforementioned model OPT–5 vidicon of Plessey Electronics, Ltd., is called "self-scanned" because shift registers **111** and **112** are built-in as a part of the unit, so that only a clock **113** and a source **114** of DC power need be applied for operation.

In FIG. **12,** box **25** represents the transducer unit and includes a plurality of selective cooling means in one-to-one correspondence with the photosensors **27** of the vidicon **23.** In FIGS. **12** and **13** the piezoelectric elements for driving any particular type of above-disclosed cooling means are shown as capacitors P_{ij} because such elements operate in a circuit essentially as lossy capacitors. As shown, one terminal of each piezoelectric element P_{ij} is coupled to a column conduction path C_i and to a row conduction path R_j through a separate transistor T_{ij} which serves as an AND gate for routing video signals to the proper element P_{ij}. While it will be understood that any of a great variety of transistors may be used, the type 2N5551 has been found to be convenient. The other terminal of each element P_{ij} in a row is connected in common to a row recharge conduction path R_{jR}. In transducer unit **25,** row and column conduction paths R_j and C_i are driven, respectively, by a second horizontal shift register **115** and a second vertical shift register **116** which are slaved by conductors **117** and **118** to operate in synchronism with shift registers **111** and **112,** respectively, of vidicon **23.** The time-division multiplexed video signal from each photosensor **27** is conveyed via a single conduction path **119** to the vertical shift register **116** of transducer unit **25** which gates that video signal onto the proper row conduction path R_j. Low voltage DC power, e.g., −6 volts, is supplied to transducer unit **25** from source **114** and high voltage power, e.g., 150 volts, is supplied from a separate DC source included in a "Recharge Means" **120** (described in detail below) for driving piezoelectric elements P_{ij}.

In operation, row conductors R_j normally are maintained at a given voltage, e.g., zero volts, by shift register **116;** and column conductors C_i are maintained at a more negative voltage, e.g., −6 volts, by shift register **115,** so that transistors T_{ij} are turned off. Recharge lines R_{jR} normally are maintained at a large positive voltage, e.g., 150 volts, by recharge means **120.**

At the instant any particular photosensor **27,** e.g., the upper left one, is being scanned, its signal output, assumed to be negative, is gated onto video line **119** and to shift register **116.** At the same time, shift register **115** increases the voltage on column conductor C_1, e.g., to −3 volts; and shift register **116** decreases the voltage on row conductor R_1, e.g., to −3 volts, such that transistor T_{11} is placed in a "marginally on" condition. All other transistors remain off, with at least **3** volts reverse bias on their emitter-base junctions. At this same time the negative video signal from line **119** is gated onto and simply adds in a minus voltage direction to the voltage on row conductor R_1. This video signal turns on transistor T_{11} to a degree dependent on the size of the video signal. The current drawn through T_{11} discharges piezoelectric capacitance P_{11} by an amount proportional to the video signal.

At the next clock pulse, shift register **115** restores the voltage on C_1 to −6 volts and decreases the voltage on C_2 to −3 volts so that the video signal from the next photosensor turns on transistor T_{12} and discharges piezoelectric capacitor P_{12}.

At this point, it is convenient to define a "frame time" as the time required to scan the entire vidicon and transducer once. With this definition in mind, recharge means **120** is adapted for operation in accordance with this invention as follows. Recharge means **120** is adapted such that approximately one-half frame after a row, e.g., R_1, has been scanned, the voltage on the recharge line, e.g., R_1, corresponding to that row is reduced, e.g., to zero, for a short time so that all the piezoelectric capacitors, e.g., P_{ij} of that row are recharged. The recharging of the capacitors occurs because the reduction in voltage on the recharge line forward biases the collector-base junctions of all transistors in the row coupled to that line; and a pulse current flows from horizontal shift register **115**, down column conductors C_i, through the forward biased base-collector junctions of the transistors, and through the capacitors into the recharge line.

In this manner, in each frame scan, each piezoelectric element experiences a momentary discharge current proportional to the video signal and, a half frame thereafter, experiences a recharge current of the same magnitude as the discharge current but of opposite polarity. The result is that each piezoelectric element experiences a square wave driving voltage (current) that is proportional to the light intensity incident on its corresponding photosensor. Advantageously, in accordance with this invention, the frequency of frame scanning is made equal to the resonant frequency of the vibrating reeds for efficient operation and so that no separate generator of periodic voltages for driving the reeds is required. This leads to an economy of equipment and power consumption.

A final word now about recharge means **120**, which may be implemented as follows. Without loss of generality, assume ten rows in transducer **25**. Then when the voltage on any row conductor, e.g., R_7, is reduced to −3 volts, this reduction can be used to trigger a one-shot multivibrator which momentarily reduces the voltage on the recharge line, i.e., R_{2R}, which occurred one-half frame earlier for recharging that line. Likewise, when row conductor R_3 is accessed, the voltage on recharge line R_{8R} momentarily is reduced for recharging piezoelectric capacitors P_{8j}. Further details will be apparent to those skilled in the art.

Using the principles taught hereinabove with respect to selective cooling, a hearing substitution system for the totally deaf also is feasible. FIGS. **14** and **15** show, respectively, a block circuit diagram and an advantageous transducer array for such apparatus in accordance with this invention. As shown in FIG. **14**, an exemplary form of such apparatus includes a microphone **131**, the signal from which is first amplified through an amplifier **132** and then filtered into desired component frequencies by a bank of filters **133**. The output of each filter than is converted into a DC voltage by one of a plurality of peak detectors **134A**, **134B**,...**134N**. An air pump driver **135** supplies a suitably periodic signal for driving the individual cooling pumps of the transducer unit **141** of FIG. **15**; and this periodic signal is amplitude-modulated by a plurality of modulators **136** in accordance with each of the plurality of outputs of peak detectors **134** to produce a corresponding plurality of amplitude-modulated periodic signals for driving the individual cooling pumps of transducer unit **141** in FIG. **15**.

For a hearing substitution system, disposing the cooling elements over a portion of the skin along a helix, as indicated in FIG. **15**, is advantageous. It is also advantageous to design the filters with bandpasses such that their outputs correspond to the seven notes of the musical scale and then to have seven cooling elements in each turn of the helix, as shown in FIG. **15**, such that any given note and its harmonics are represented on a line radially from the center of the helix. In FIG. **15**, the cooling elements, for simplicity and clarity, are labeled with the musical note to which they correspond, C_4 being "middle C" or 256 cycles per second.

With this design, in accordance with this invention, if the audio input to microphone **131** is a pure middle C, only element C_4 will be activated to produce cooling. If the input contains middle C and harmonic overtones, then cooling elements C_4, C_5, C_6, etc. will be activated. Other notes produce similar effects along lines at different angles. Thus the pitch of the sound is indicated by the angle of the active cooling elements and the overtones are indicated by the number of active cooling elements along any given radial line. A sibilant sound containing a mixture of high frequencies will activate a group of cooling elements near the center of the helix. Through a learning process, a person can quickly learn to recognize the tone and timbre of musical sounds. A person also can learn to recognize at least simple speech sounds in a manner analogous to the way that an ordinary trained ear does, i.e., by learning to recognize the resonance peaks in the sound (here, degree of cooling) introduced by the speaker's oral cavities.

Other transducer arrays, of course, can be used with the system of FIG. **14**. For example, a matrix as shown in FIG. **2** can be used, with each row representing any desired frequency and its harmonics and subharmonics. However, the fact that the helix arrangement of FIG. **15** approximates the transmission characteristics of the aural cavity of the human ear is one important reason why it is presently preferred. Of course, any of the cooling means heretofore disclosed may be used in this hearing substitution system as well as in the vision substitution systems.

While the foregoing has been primarily in terms of complete optical and auditory systems, it will be appreciated that operation of a selective cooling transducer unit with signals from a recording, such as from paper or magnetic tape, also is within the spirit and scope of this invention.

Also, it will be understood that a selective cooling transducer unit can be used within this invention for displaying optical color information on the skin. In addition to the apparatus of FIG. **1**, color filters can be used in conjunction with the vidicon for selectively filtering and displaying color information, as desired, e.g., in a manner analogous to the filtering of speech frequencies illustrated in FIG. **14**.

And, of course, once a subject has learned to construct mental images automatically and subconsciously, the apparatus can be used with recorded information for subliminal learning while asleep.

In a sophisticated approach to vision substitution, two transducer units can be used on different parts of

the body, one being driven from a wide angle, low resolution camera and the other being driven from a narrow angle, high resolution camera. In a manner analogous to operation of a normal human eye, when an object of interest appears in the low resolution camera, the person can train his high resolution camera on the object and, in a sense, "focus-in" on the object of interest.

In operating apparatus of the type depicted in FIGS. 1–7, in certain warm ambients, the intensity of cooling may not be as great as desired. For better results, the disclosed transducer unit is simply covered with a closed air space into which mildly refrigerated air is introduced for use in air exchange when the pumps operate. Also, of course, although such is not preferred, heated air could be introduced into the air space and the transducer unit could then operate as selective heating apparatus.

Inasmuch as the foregoing paragraph is directed essentially to sensitivity of the apparatus, it is appropriate at this point to mention a heretofore unmentioned advantage and dimension of this invention. It is found that at high vibrational amplitudes the forced convective cooling also produces sufficient hair displacement to impart a tactile sensation to the skin-nervous system complex. This tactile sensation is distinguishably different from the concurrent cooling sensation and thus can be used in conjunction with the cooling for imparting additional distinct information suitably coded, or simply for enhancing sensitivity to the information intended to be imparted through cooling.

While certain specific embodiments have been described, the detail is intended to be, and will be understood to be, instructive rather than restrictive. As will be understood, all modifications within the scope and spirit of the teachings and claims are properly considered as part of this invention.

A modification which is particularly apparent is that, of course, the vibrating discs of this invention can be driven by any of a great variety of means in addition to those described, such as, for example, electrostatically or electromagnetically, and with or without using the vibrating reeds.

And, of course, with respect to the piezoelectric embodiments described, it will be apparent that the reeds can be mounted on the piezoelectric elements at angles other than those shown for achieving, for example, nested sets of pumps and potentially more compact transducer units.

And, finally, it should be appreciated that a great variety of materials, including simply air, can be used as the thermally insulating medium of this invention. For example, in the hat-brim embodiment mentioned hereinabove, the pumps were suspended from the hat brim and spaced from the forehead with only a relatively dead air-space between the forehead and the entire array of pump nozzles. This, of course, suggests that the thermally insulating medium need not be apertured in the sense of having physical voids, but rather apertured in the sense that heat can be selectively gated therethrough in accordance with signal information for achieving the selective cooling.

What is claimed is:

1. Apparatus for converting information signals into distinguishable, localized cooling of a receptive heat-producing medium comprising, in combination:

means for detecting the information signals;

thermal insulating means covering and substantially enclosing a portion of the medium for reducing the rate of heat lost by the medium to its ambient; and

a plurality of control means associated with the insulating means and responsive to the detection means for selectively varying the rate of heat loss through the insulating means by distinguishable portions of the medium in response to the information contained in the information signals.

2. Apparatus as recited in claim **1** wherein the apparatus includes means for detecting electrical information signals.

3. Apparatus as recited in claim **1** wherein the insulating means includes a thermally insulating material having a plurality of apertures therethrough.

4. Apparatus as recited in claim **3** wherein the plurality of control means includes a plurality of units, each unit being associated with a separate one of the apertures.

5. Apparatus as recited in claim **4** wherein a unit includes:

a disc of diameter less than the diameter of the aperture with which it is associated;

vibratory means coupled to the disc and responsive to the detection means for vibrating the disc in a mode longitudinal with respect to the axis of the aperture with amplitude of vibration proportional to the information contained in the information signals.

6. Apparatus as recited in claim **5** wherein the vibratory means includes a piezoelectric element and a vibrating reed having one end coupled to the disc and the other end coupled to the piezoelectric element.

7. Apparatus as recited in claim **6** wherein the detection means additionally includes a plurality of photosensitive means for detecting light energy and for converting said light energy into electrical signals representative thereof.

8. Apparatus as recited in claim **3** wherein the control means includes:

means for covering at least partially an aperture in the thermal insulating means for enabling the air therein to be quiescent and to be heated by heat from the heat-producing medium; and

means responsive to the detection means for selectively cooling by forced convection the air in said aperture by an amount representative of the information contained in said information signals.

9. Apparatus as recited in claim **8** wherein the means for covering and selectively cooling by forced convection include:

a piezoelectric element;

a reed having one end attached to one end of the piezoelectric element; and

a disc of diameter about the same as but less than the diameter of the aperture with which it is associated connected to the other end of the reed such that vibration of the reed in response to vibration of the piezoelectric element causes the disc to translate longitudinally with respect to the axis of the aperture.

10. Apparatus as recited in claim **8** wherein the means for selectively cooling by forced convection includes:

an air duct having an opening directed into said aperture;

means for supplying said air duct with pressurized air;

a shutter of about the same size as the diameter of the aperture disposed between the aperture and the opening in said air duct for simultaneously covering the aperture and preventing air from the air duct from substantially agitating the air in the aperture; and

means coupled to the shutter and responsive to the detection means for selectively moving the shutter to at least partially uncover the aperture and allow air from the air duct to agitate the air in the aperture so that selective cooling of that portion of the heat producing medium under the aperture is selectively cooled in an amount representative of the information contained in the information signals.

11. Apparatus as recited in claim **10** wherein the means for moving the shutter includes means for moving the shutter in a vibratory mode.

12. Apparatus as recited in claim **8** wherein the means for selectively cooling by forced convection includes:

a cylinder having a relatively large aperture therein and a relatively small aperture therein, the small aperture being directed toward the aperture in the thermal insulating material;

a disc of about the same size as, but smaller than, the large aperture; and

means for vibrating the cross-section of the disc in and out of the large aperture for selectively forcing air out of the small aperture and into the aperture in the thermal insulating material for selectively agitating the air therein for selectively cooling the portion of the heat-producing medium thereunder in accordance with information contained in the information signals.

13. Apparatus as recited in claim **12** wherein the vibrating means includes a piezoelectric element and a vibrating reed having one end coupled to the piezoelectric element and the other end coupled to the disc.

14. Apparatus as recited in claim **12** wherein the vibrating means includes means for moving the disc along the cylindrical axis of the large aperture.

15. Apparatus as recited in claim **8** wherein the apertures, covering means, and cooling means are disposed in an array of rows and columns.

16. Apparatus as recited in claim **15** additionally comprising:

piezoelectric means for driving each covering means to produce the selective cooling in said aperture;

a first plurality of row conduction paths, separate ones being disposed along each row;

a first plurality of column conduction paths, separate ones being disposed along each column;

a plurality of AND gates, separate ones coupling each piezoelectric means to a row conduction path and to a column conduction path; and

a second plurality of row conduction paths, separate ones connected in common to each piezoelectric element in each respective row.

17. Apparatus as recited in claim **16** additionally comprising:

first shift register means coupled to the first plurality of row conduction paths for applying control and signal information thereto;

second shift register means coupled to the column conduction paths for applying control information thereto; and

recharge means coupled to the second plurality of row conduction paths for applying thereto signals for recharging the piezoelectric elements.

18. Apparatus as recited in claim **8** wherein the covering means and cooling means include:

an apertured rigid plate having at least one aperture registered with at least one aperture in the thermally insulating medium;

a piezoelectric element fixedly mounted onto said plate; and

a disc of diameter about the same as the diameter of the aperture in the rigid plate coupled to the piezoelectric element in such a manner that application of sufficient periodic voltage to the piezoelectric element produces vibratory movement of the disc with respect to the aperture.

19. Apparatus as recited in claim **3** wherein the control means includes:

means for covering the apertures in the thermal insulating material with a radiation absorbing material;

radiation reflecting means spaced from the radiation absorbing material by less than one-fourth wavelength of the radiation from the heat producing medium; and

means responsive to the detection means for causing the spacing to approach one-fourth wavelength over selected ones of the apertures in response to information contained in the information signals such that selective cooling by selective absorption of radiation thereby is enabled.

20. Apparatus as recited in claim **3** wherein the control means includes:

radiation reflecting shutters disposed one over each of the apertures in the thermal insulating material;

a radiation absorbing layer disposed over and spaced from the shutters and from the surface of the thermal insulating medium; and

means responsive to the detection means for selectively at least partially moving selected ones of said shutters away from the aperture openings for controlling heat loss by radiation such that selective cooling of selected portions of the surface of the heat producing medium thereby is enabled in response to information contained in the information signals.

21. Apparatus as recited in claim **20** wherein the means for moving the shutters includes in combination with each shutter a piezoelectric element and a vibrating reed having one end coupled to the piezoelectric element and the other end coupled to the shutter.

22. Apparatus as recited in claim **3** wherein the control means includes:

a semiconductor covering each aperture in the thermal insulating material and a reflecting material on the outside surface of the semiconductor for returning radiation to the surface of the heat producing medium; and

means responsive to the detection means for generating electron-hole plasma in selected portions of the semiconductor over selected apertures for causing selective absorption of radiation in those portions of the semiconductor for causing selective cooling of the portions of the surface of the heat producing medium under said selected portions in response to information contained in the information signals.

23. Apparatus as recited in claim **2** wherein the detection means includes:

means for converting auditory energy into electrical signals;

means for filtering said electrical signal into a plurality of electrical signals, each being representative of the extent to which said electrical signal included a desired component frequency;

means for detecting the peak value of each of said plurality of electrical signals and for converting each of said signals into a DC electrical signal representative of the peak value of said each one;

means for amplitude-modulating a periodic electrical signal with each of said DC signals so as to produce a plurality of periodic signals whose amplitudes are proportional to the DC voltage level of said DC signals; and

means for rendering the control means responsive to the amplitude-modulated signals.

24. Apparatus as recited in claim **23** wherein the control means are disposed along a helix.

25. Apparatus for converting information signals into distinguishable, localized cooling of a receptive heat-producing medium comprising, in combination:

means for detecting the information signals;

thermal insulating means for covering a portion of the medium for reducing the rate of heat lost by the medium to its ambient; and

a plurality of control means associated with the insulating means and responsive to the detection means for selectively varying the rate of heat loss through the insulating means by distinguishable portions of the medium in response to the information contained in the information signals; and wherein:

the insulating means includes a thermally insulating material having a plurality of apertures therethrough;

the plurality of control means includes a plurality of units, each unit being associated with a separate one of the apertures and each unit including: a disc of diameter less than the diameter of the aperture with which it is associated; and

vibratory means coupled to the disc and responsive to the detection means for vibrating the disc in a mode longitudinal with respect to the axis of the aperture with amplitude of vibration proportional to the information contained in the information signals.

26. Apparatus for converting information signals into distinguishable, localized cooling of a receptive heat-producing medium comprising, in combination:

means for detecting the information signals;

thermal insulating means for covering a portion of the medium for reducing the rate of heat lost by the medium to its ambient; and

a plurality of control means associated with the insulating means and responsive to the detection means for selectively varying the rate of heat loss through the insulating means by distinguishable portions of the medium in response to the information contained in the information signals; and wherein:

the insulating means includes a thermally insulating material having a plurality of apertures therethrough;

the control means includes:

means for covering at least partially an aperture in the thermal insulating means for enabling the air therein to be quiescent and to be heated by heat from the heat-producing medium; and

means responsive to the detection means for selectively cooling by forced convection the air in said aperture by an amount representative of the information contained in said information signals; and

the means for covering and selectively cooling by forced convection include:

a piezoelectric element;

a reed having one end attached to one end of the piezoelectric element; and

a disc of diameter about the same as but less than the diameter of the aperture with which it is associated connected to the other end of the reed such that vibration of the reed in response to vibration of the piezoelectric element causes the disc to translate longitudinally with respect to the axis of the aperture.

27. Apparatus for converting information signals into distinguishable, localized cooling of a receptive heat-producing medium comprising, in combination:

means for detecting the information signals;

thermal insulating means for covering a portion of the medium for reducing the rate of heat lost by the medium to its ambient; and

a plurality of control means associated with the insulating means and responsive to the detection means for selectively varying the rate of heat loss through the insulating means by distinguishable portions of the medium in response to the information contained in the information signals; and wherein:

the insulating means includes a thermally insulating material having a plurality of apertures therethrough;

the control means includes:

means for covering at least partially an aperture in the thermal insulating means for enabling the air therein to be quiescent and to be heated by heat from the heat-producing medium; and

means responsive to the detection means for selectively cooling by forced convection the air in said aperture by an amount representative of the information contained in said information signals; and

the means for selectively cooling by forced convection includes:

an air duct having an opening directed into said aperture;

means for supplying said air duct with pressurized air;

a shutter of about the same size as the diameter of the aperture disposed between the aperture and the opening in said air duct for simultaneously covering the aperture and preventing air from the air duct from substantially agitating the air in the aperture; and

means coupled to the shutter and responsive to the detection means for selectively moving the shutter to at least partially uncover the aperture and allow air from the air duct to agitate the air in the aperture so that selective cooling of that portion of the heat producing medium under the aperture is selectively cooled in an amount representative of the information contained in the information signals.

28. Apparatus for converting information signals into distinguishable, localized cooling of a receptive heat-producing medium comprising, in combination:

means for detecting the information signals;

thermal insulating means for covering a portion of the medium for reducing the rate of heat lost by the medium to its ambient; and

a plurality of control means associated with the insulating means and responsive to the detection means for selectively varying the rate of heat loss through the insulating means by distinguishable portions of the medium in response to the information contained in the information signals; and wherein:

the insulating means includes a thermally insulating material having a plurality of apertures therethrough;

the control means includes:

means for covering at least partially an aperture in the thermal insulating means for enabling the air therein to be quiescent and to be heated by heat from the heat-producing medium; and

means responsive to the detection means for selectively cooling by forced convection the air in said aperture by an amount representative of the information contained in said information signals; and

the means selectively cooling by forced convection includes:

a cylinder having a relatively large aperture therein and a relatively small aperture therein, the small aperture being directed toward the aperture in the thermal insulating material;

a disc of about the same size as, but smaller than, the large aperture; and

means for vibrating the cross-section of the disc in and out of the large aperture for selectively forcing air out of the small aperture and into the aperture in the thermal insulating material for selectively agitating the air therein for selectively cooling the portion of the heat-producing medium thereunder in accordance with information contained in the information signals.

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