

[54] **SUBJECT INTEGUMENT SPATIAL
STIMULATOR**

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178/DIG. 32, 340/407**

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[58] Field of Search **3/1; 128/1 R, 404, 418,
128/419 R, 423; 178/DIG. 32; 340/407**

[56] **References Cited**

UNITED STATES PATENTS

2,703,344 3/1955 Anderson 128/404

3,612,061 10/1971 Collins et al. 128/418
3,699,970 10/1972 Brindley et al. 128/149 R

Primary Examiner—William E. Kamm
Attorney, Agent, or Firm—Bailin L. Kuch

[57] **ABSTRACT**

A cutaneous stimulator includes a plurality of pairs of first and second immediately adjacent, noncontiguous contacts, the plurality of said first contacts being arranged in columns and the plurality of said second contacts being arranged in rows, each of the contacts in each respective column being interconnected and each of the contacts in each respective row being interconnected, and means for energizing selected columns and rows, whereby the respective pairs of contacts at the respective intersections of said columns and rows are adapted to cutaneously stimulate a subject.

6 Claims, 3 Drawing Figures

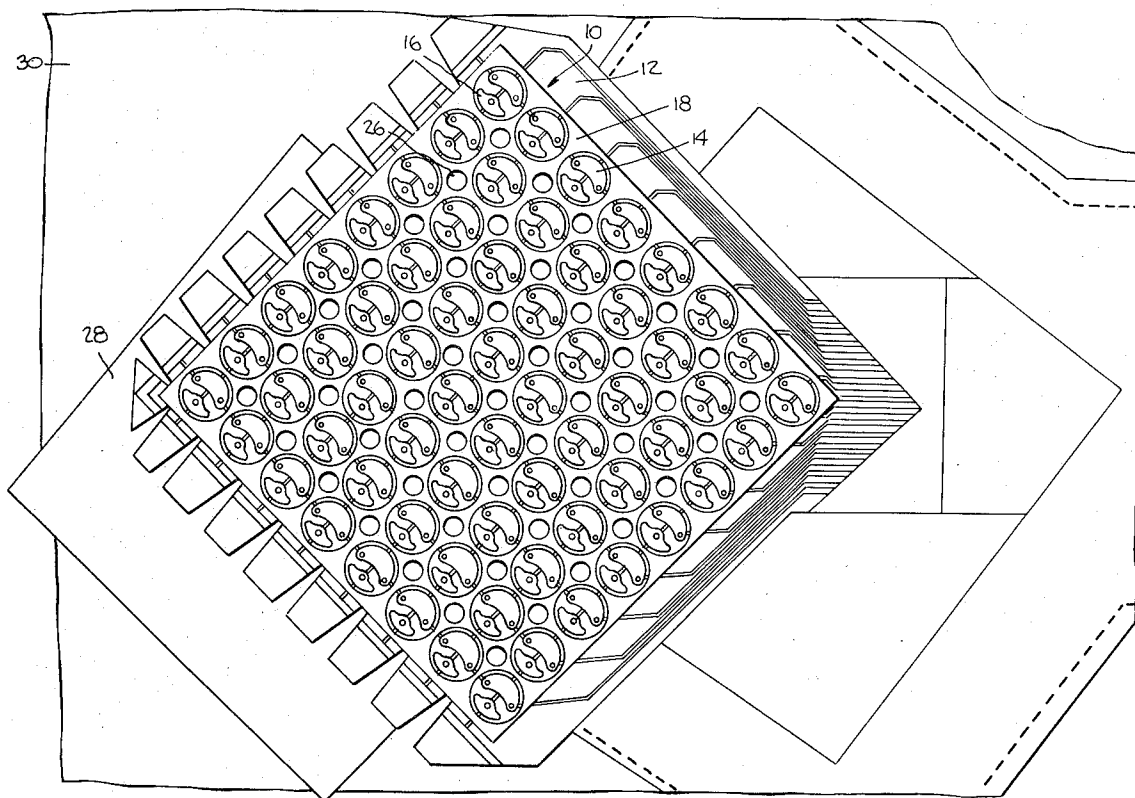


Fig. 1.

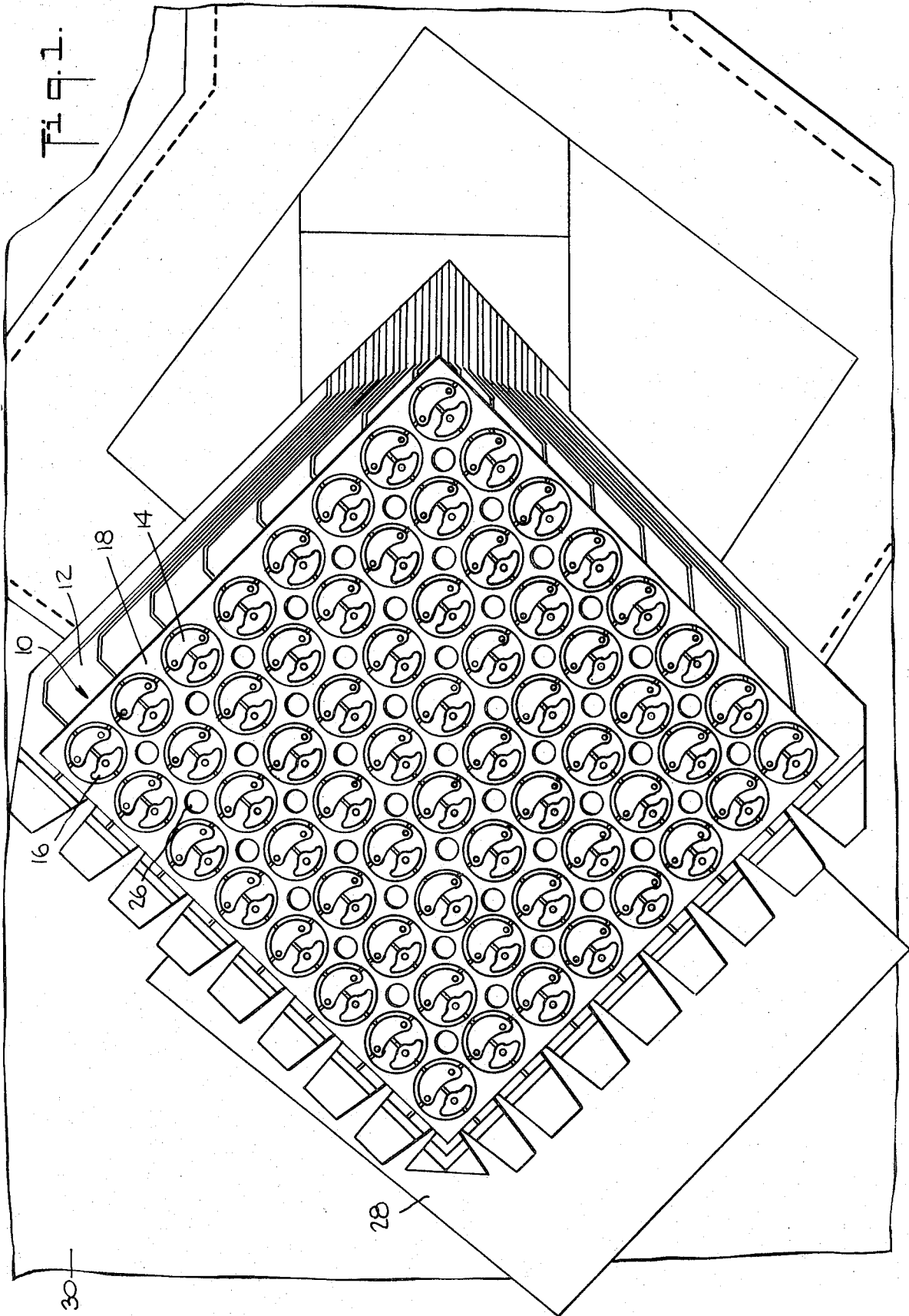


FIG. 2.

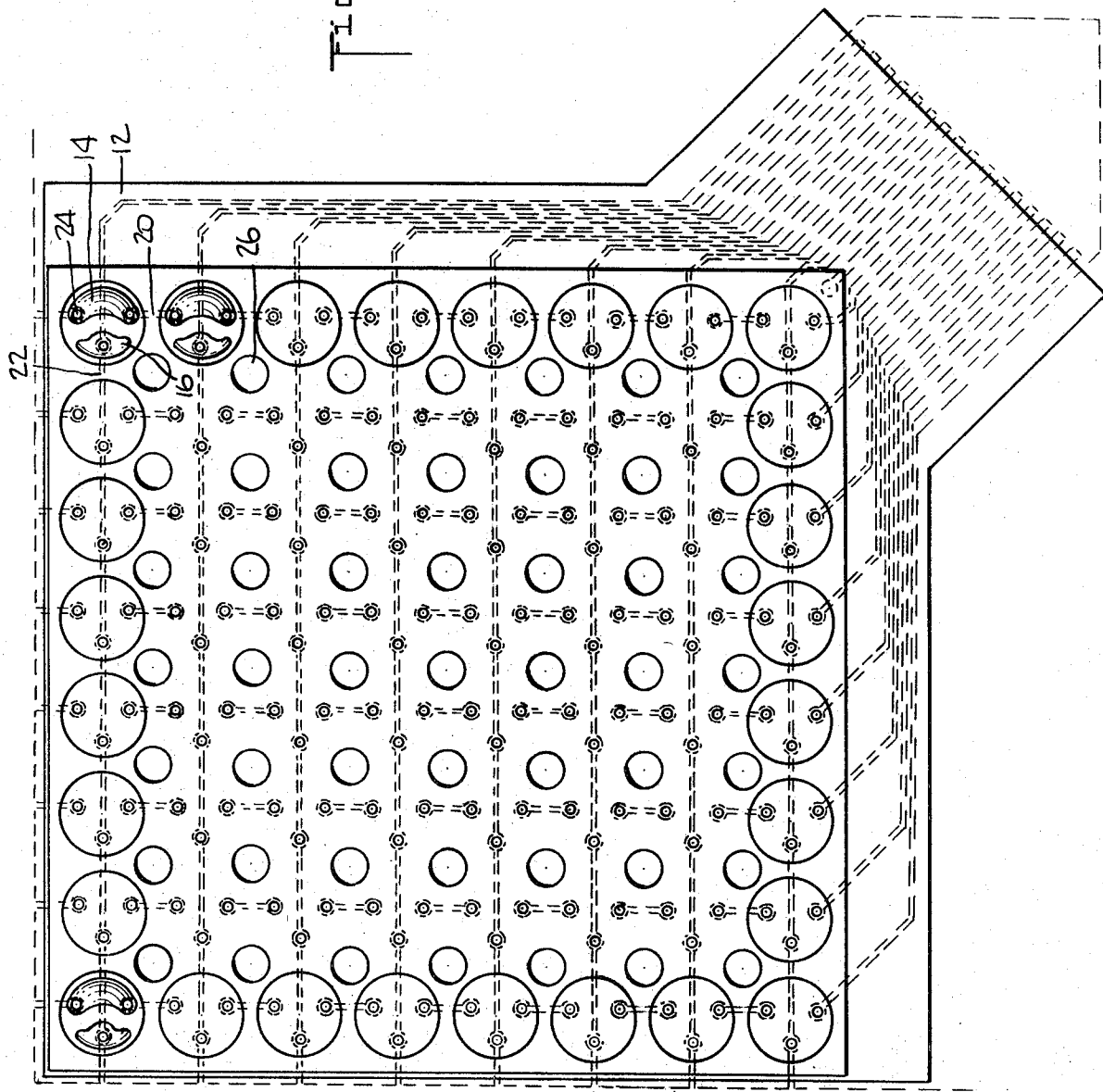
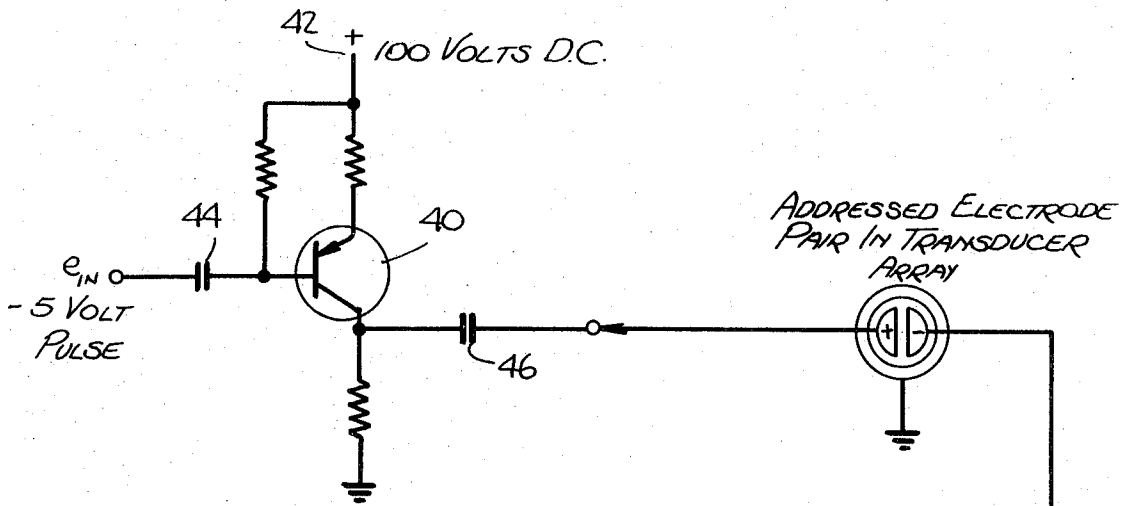
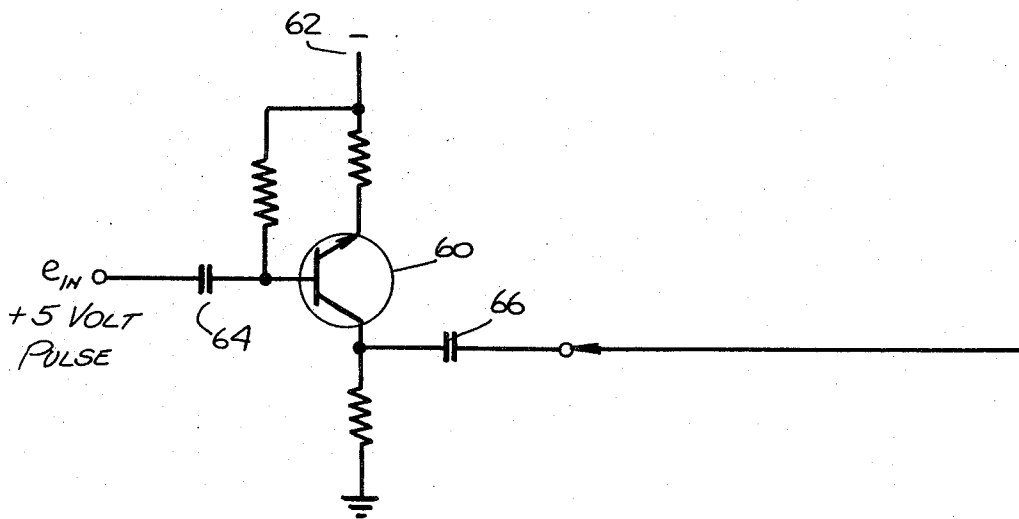


Fig. 3.

"X" DRIVER (ROWS)



"Y" DRIVER (COLUMN)



SUBJECT INTEGUMENT SPATIAL STIMULATOR**BACKGROUND OF THE INVENTION****1. Field of the Invention**

This invention is directed at a system for providing a two dimensional matrix of point stimulation to the skin of a subject, i.e., cutaneous signaling.

2. Description of the Prior Art

Cutaneous signaling is well known, and is described, for example, in U.S. Pat. No. 2,703,344 issued to A. B. Anderson on Mar. 1, 1955 and in U.S. Pat. Nos. 3,612,061 and 3,628,193 issued to C. C. Collins on Oct. 12, 1971 and Dec. 21, 1971 respectively. Anderson describes one system which deals primarily with a sound perception system for the totally deaf which subdivides the sound into frequency bands and measures the amplitude of each band. An orthogonal array of electrodes is used to convey this information to the skin of the subject in a bar graph pattern of electrical stimulation at a fixed frequency. Each electrode column designates a respective frequency band and the number of electrodes excited in the respective column indicates the amplitude of the respective band. The circuit utilized requires a separate oscillation amplifying tube to drive each electrode, or a separate anode in a multi-element beam switching tube, and may be characterized as individual electrode addressing, with the particular electrode selected by the electronic circuitry prior to the driver amplifiers. Anderson describes another system dealing with an object detector for the blind incorporating ultrasonic pulse transmission, reception and signal processing to provide differential stimulation of electrodes on both shoulders, with the range coded as stimulation amplitude, and the bearing coded as differential amplitude.

Collins, in U.S. Pat. No. 3,628,193, describes a complete video detector and conversion system utilizing a multi element beam switching tube to drive individual output electrodes for two-dimensional cutaneous stimulation. In U.S. Pat. No. 3,612,061, Collins describes his electrode array as coaxial electrodes in an orthogonal array supported by a flexible material. A compressible backing is provided between the electrodes and a more rigid cover material so as to maintain contact pressure between the electrodes and the skin. A separate transistor amplifier is required for each electrode.

SUMMARY OF THE INVENTION

An object of this invention is to provide a cutaneous stimulator having a flexible, orthogonal matrix of individual points, and requiring the minimum number of electrode driver amplifiers.

Another object of this invention is to provide such a stimulator with good cutaneous contact between the skin and the electrodes, adequate ventilation for prolonged use, light weight and ease of manufacture.

A feature of this invention is the provision of a cutaneous stimulator including a plurality of pairs of first and second immediately adjacent, noncontiguous contacts, the plurality of said first contacts being arranged in columns and the plurality of said second contacts being arranged in rows, each of the contacts in each respective column being interconnected and each of the contacts in each respective row being interconnected, and means for energizing selected columns

and rows, whereby the respective pairs of contacts at the respective intersections of said columns and rows are adapted to cutaneously stimulate a subject.

BRIEF DESCRIPTION OF THE DRAWING

These and other objects, features and advantages of the drawing will be apparent from the following specification taken in conjunction with the accompanying drawing in which:

FIG. 1 is an exploded view of an assembly embodying the invention;

FIG. 2 is plan view of the conductor matrix subassembly of FIG. 1; and

FIG. 3 is a schematic diagram of exemplary drivers for a column and row to provide a signal at a selected pair of contacts.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The subject of this invention is a flexible electrodermal stimulator array which drastically reduces the number of transistor electrode driver amplifiers required through cross bar addressing of the rows and columns of the orthogonal matrix while providing good continuous contact between skin and electrodes, adequate ventilation for prolonged use, light weight and ease of manufacture.

In order to understand the advantages afforded by a cross bar addressed electrode array one must first become familiar with the electro-transduction requirements of the skin. First, AC coupling must be employed to prevent blistering, scarring, or other tissue damage. Second, an initial peak AC potential between 100 and 200 volts must be applied to start conduction through the outer layer of untreated skin. Third, the current delivered must be externally limited (by the driver amplifier circuit) once conduction is initiated, so as to remain at a level below the threshold of pain. Fourth, the sensate level of stimulation between the thresholds of touch and pain varies with current level and pulse duration. Fifth, both the thresholds of touch and pain vary inversely with pulse duration in such a way that constant current stimulation provides a wider dynamic range than constant pulse width. Sixth, although the time constant of cutaneous neural stimulation is between 1 and 2 milliseconds, pulse repetition rates in excess of 60 hertz produce fading and loss of sensation which is restored only after the site of stimulation is changed. Seventh, electrodes must be spaced at least 6 millimeters apart on the abdomen and 10 millimeters apart on the back to provide distinguishable two point sensation. Eighth, skin resistance varies inversely and skin capacitance directly with the area of the electrodes employed. Ninth, pattern perception requires sequential rather than simultaneous excitation of the electrodes in the two dimensional array.

If the center electrodes of a single column in the matrix taught by the prior art are addressed with a positive pulse while the annular rings of a single row are grounded, so as to produce punctate stimulation at the locus of intersection of the column and row, the outer layer of skin will break down at multiple points and the sensation will appear to encompass the entire column. However, cross bar addressing can be achieved if the electrode at each point defined by the intersection of a column and a row in the array is bifurcated into first and second contacts, with each first contact intercon-

nected with adjacent first contacts in its column and each second contact interconnected with adjacent second contacts in its row, and the split halves of each electrode are insulated from one another and from the surrounding ground plane. Since the breakdown threshold lies between 100 and 200 volts, a 100 volt positive pulse may be applied to all of the first contacts in a single column without initiating conduction to the surrounding ground potential plane. Similarly, a minus 100 volt pulse may be applied to all of the second contacts in a single row without initiating conduction to the surrounding ground potential plane. However, at the point where the column and row intersect a potential difference of 200 volts will be impressed upon the skin between the first and second contacts of the electrode at that location. This voltage is sufficient to cause breakdown and initiate conduction. The level of current delivered must, of course, be limited by the transistor driver circuitry employed.

FIGS. 1 and 2 show a preferred embodiment of the complete flexible electrodermal transducer array 10. The array is made from a flexible sheet of insulating material 12 (such as Teflon or Mylar) with the split electrode of first contacts 14 and second contacts 16 and ground plane 18 pattern etched from conducting foil on one side and the column interconnecting links 20 and the row interconnecting links 22 similarly etched from conducting foil on the reverse side. Interconnections through the insulating material may be made by tiny plated through holes 24 or other means. The foil for use in contact with the skin is plated with an inert metal (such as silver or gold) to preclude corrosion by skin reagents. In addition to the holes 24 supplied for interconnection, larger air circulation or ventilation holes 26 are located in the ground plane between each diagonally adjacent pair of electrodes. This flexible electrode array with orthogonal foil interconnections and air ventilation holes is held in intimate contact with the skin of the abdomen, by ventilated cushioning 28 (such as flexible foam or sponge material) and a similarly ventilated outside covering material 30 (such as canvas or cloth) with fastening means for holding it in place on the body. Such a double sided flexible printed circuit is easy to manufacture by known photo etching and plating techniques, as shown, for example, in U.S. Pat. No. 3,514,425 issued to V. Vodicka on June 2, 1970. It thus constitutes a much simpler and less costly electrodermal transducer array than any known heretofore.

It may be noted that the split electrode pattern need not consist of perfect semicircular segments to achieve cross bar addressing. The gap between the electrode halves may be a straight line, a C shaped curve, an S shape or even a circle. Best results will be achieved if the two electrode halves are of equal area. Of course a semicircular configuration provides the maximum electrode area within a given diameter cutout from the surrounding ground plane. The gap between the electrode halves and between each electrode and the surrounding ground potential plane must be wide enough to prevent breakdown of the flexible insulating material to which the foil is attached. This material need not be planar and, as here shown, each electrode may be dimpled in order to provide improved good body contact.

The exemplary prior art requires a 300 volt transistor, an output coupling capacitor, a collector load resistor

and an emitter current limiting resistor, together with a clamped base voltage drive for each electrode of the array. Whereas 1024 such transistor amplifier stages will be required by a 32 by 32 matrix, the same matrix employing cross bar addressing as disclosed herein will require only 64 such electrode driver amplifier stages. In addition, the transistors employed need only have a 100 to 150 volt breakdown rating. In order to provide positive polarity pulses to a single column of first contacts, without dissipating power in the amplifier stage during the period between pulses, a PNP transistor 40 should be employed with a positive polarity bias source 42 (typically 100 volts) interconnected as shown in FIG. 3. This driver amplifier circuit may be turned on through capacitive coupling means 44 by a negative going 5 volt pulse such as the typical output signal from a 5 volt integrated circuit logic gate. As may be seen from the circuit interconnection, the emitter current of the transistor will be limited to the capacitively coupled base drive voltage pulse amplitude, minus the base to emitter voltage drop, all divided by the resistance value of the resistor connected between the positive bias supply and the emitter of the transistor. When the output coupling capacitor 46 is unloaded, most of the emitter current will flow through the base to the input coupling capacitor. When the output coupling capacitor 46 is connected through the transducer electrode and skin resistance to a negative polarity current drain, most of the emitter current will flow through the collector to the output coupling capacitor (with a small amount flowing through the collector load resistance to the ground potential terminal). By this means the output current pulse through the stimulator electrode to the skin will be limited to a value determined by the input pulse amplitude and the value of the emitter resistor. When the transistor is thus turned on, the voltage applied through the output coupling capacitor to the skin will rapidly rise to within 5 volts of the positive bias supply.

The typical row driver stage employs identical component values connected in the same configuration to an NPN transistor 60 and a negative voltage bias source 62 of value equal to the positive supply. This transistor will be turned on by a positive going 5 volt pulse delivered through capacitive coupling means 64 from a 5 volt integrated circuit logic gate. Current will be limited by the resistor connected between the transistor emitter and the negative bias supply in the same manner as described above, and the output pulse from the output coupling capacitor 66 through the electrode to the skin will drop rapidly from ground potential to within 5 volts of the negative voltage supply. This when the positive and negative output pulses are simultaneously delivered to one column and one row of contacts, a double amplitude voltage will be impressed across the skin between the electrodes at the addressed point (where the column and row intersect), and this voltage will discretely stimulate the skin of the subject.

In addition to the solid state image sensing system for the blind described above, the cross bar addressed electrodermal stimulator array may be used with any two-dimensional pattern producing electrical signals from any two-dimensional data source. For example, an infrared camera could sense the temperature differential produced by human bodies and provide precisely oriented warning signals to a soldier on guard duty or infil-

tration patrol. Similarly, an ultrasonic transducer array used as a sensor could provide a scuba diver a two-dimensional tactile image of his surroundings at night or in murky water. Of course the electrode array would have to be contained within a watertight garment to prevent shorting of the electrodes by sea water contamination. Electromagnetic energy at higher frequencies such as that of radar could also be processed to yield a two dimensional pattern of information through the electrodermal transducer to the user. Finally, it should be noted that given sufficient resolution (enough electrode points) the solid state image sensing system for the blind may also be used for the recognition of letters and words detected by a camera worn on the head of the user and thus constitute a basic element in a reading machine for the blind

What is claimed is:

1. A cutaneous stimulator comprising:
 - a plurality of pairs of first and second immediately adjacent, noncontiguous contacts,
 - the plurality of said first contacts being arranged in columns, and
 - the plurality of said second contacts being arranged in rows,
 - each of said contacts on each respective column being interconnected, and
 - each of said contacts in each respective row being interconnected;
 - a ground plane contact means immediately adjacent and noncontiguous to each of said first and second contacts;
 - means for energizing a selected column and a selected row including
 - first means for providing a first electrical potential between the selected column and said ground

plane contact means which is less than the cutaneous breakdown threshold potential,
 second means for providing a second electrical potential between the selected row and said ground plane contact means which is less than the cutaneous breakdown threshold potential,

the sum of said first and second electrical potentials between said selected column and row being greater than the cutaneous breakdown threshold potential.

2. A stimulator according to claim 1 wherein: each of said plurality of first contacts, and each of said plurality of second contacts, has substantially the same cutaneous contact area.
3. A stimulator according to claim 1 wherein: each of said plurality of first contacts, and each of said plurality of second contacts, is substantially semi-circular in shape.
4. A stimulator according to claim 3 wherein: each of said contacts includes a convex surface for cutaneous contact.
5. A stimulator according to claim 1 wherein: said first contacts, said second contacts and said ground plane contact means are all formed of conducting material disposed on one side of a sheet of insulating material, and interconnection between contacts are all formed of conducting material disposed on the other side of said sheet of insulating material and connected therethrough to the respective contacts.
6. A stimulator according to claim 5 wherein: said contacts and said interconnection are respectively made of flexible foil.

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