United States Patent [19]

Webb et al.

[11] **3,710,209**

[45] **Jan. 9, 1973**

[54] VARIABLE CAPACITOR

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[73] Assignee: **Colorado Instruments, Inc.,** Bloomfield, Colo.

[22] Filed: **Aug. 13, 1971**

[21] Appl. No.: **171,640**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 13,091, Feb. 20, 1970, Pat. No. 3,653,038.

[52] **U.S. Cl.**.....**317/249 R,** 200/DIG. 1, 317/246, 340/365 C

[51] **Int. Cl.**.....**H01g 5/16**

[58] **Field of Search**.....317/246, 249 R, 261; 340/365 C; 200/DIG. 1

[56] **References Cited**

UNITED STATES PATENTS

3,293,640	12/1966	Chalfin	317/246
3,368,116	2/1968	Spaude	317/261
3,588,875	6/1971	Gabor	340/365 C

Primary Examiner—E. A. Goldberg
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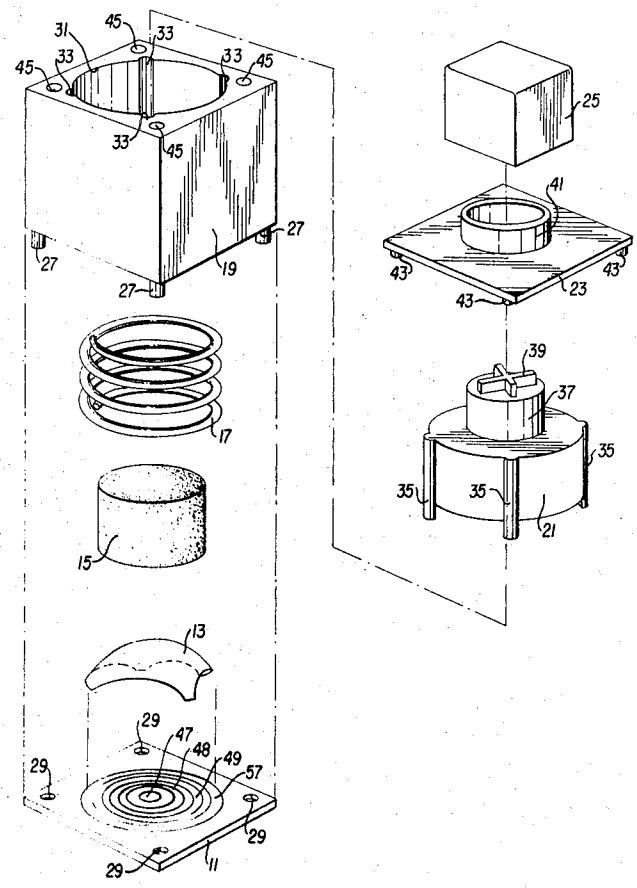
[57] **ABSTRACT**

An electrostatic impulse key suitable for use in electronic keyboards or as a separate item is described. An individual key comprises a single or plural metallic target area which may be formed on one surface of a printed circuit board. A dome spring is mounted above the metallic target and a foam cylinder is mounted between the dome spring and an actuator element. The actuator element is operated by a key mechanically connected thereto. In addition, a coil spring located about the foam cylinder between the printed circuit board and the actuator is provided for loading the actuator and key to a predetermined level prior to actuation (depression) of the key. When the key is depressed, the actuator presses the foam cylinder against the upper surface of the dome spring to cause the dome spring to change position. This position change changes the separation distance between the dome spring and the metallic target in a rapid or "snap action" manner. Because the separation distance is changed, the capacitance between the dome spring and the metallic target increases to cause a rapid decrease in a voltage connected between the dome spring and the target. This voltage decrease is in the form of a signal pulse and is suitable for use in electronic keyboard subsystems.

15 Claims, 7 Drawing Figures



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SHEET 1 OF 2

FIG. 1

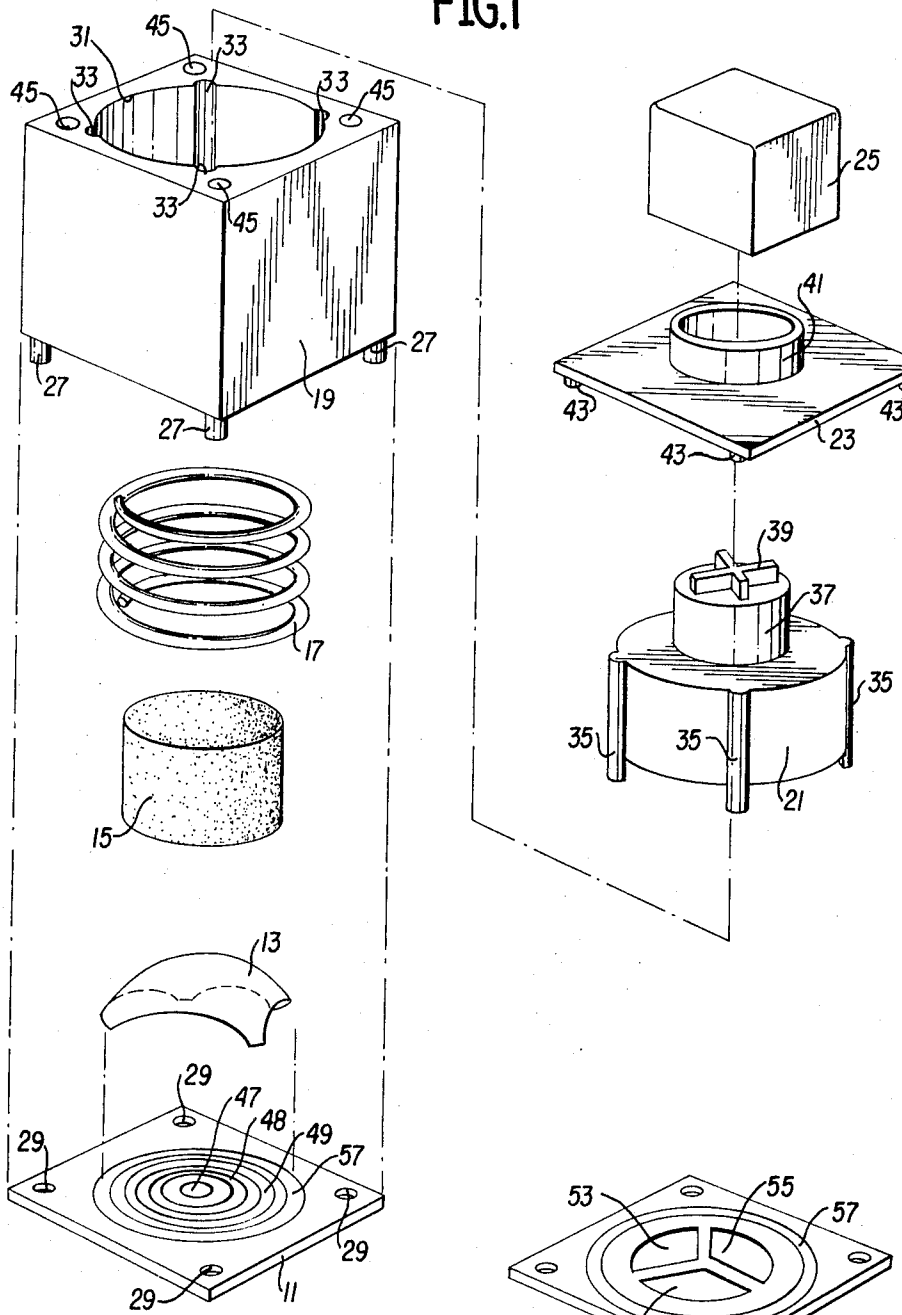

FIG. 3

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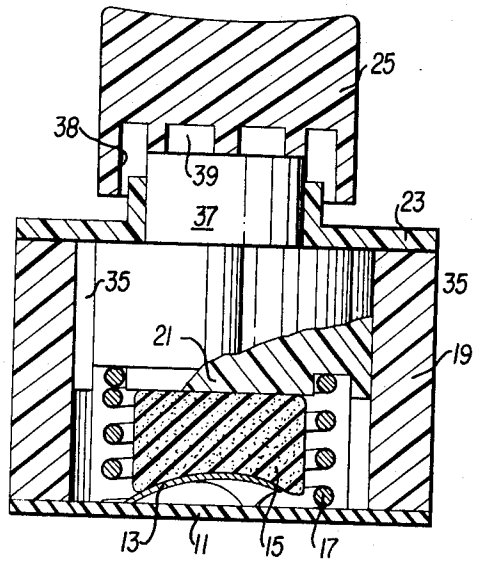


FIG.2

FIG.7

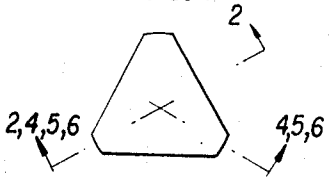


FIG.4

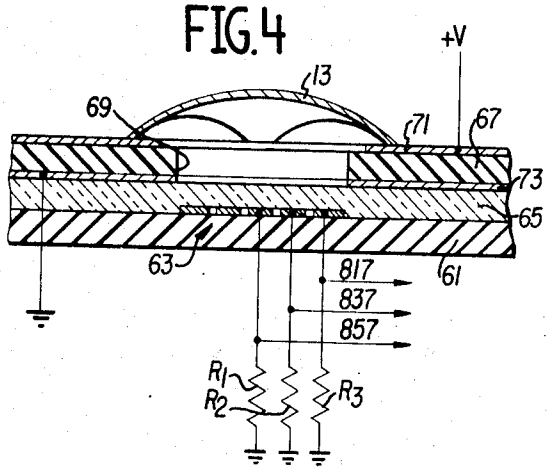
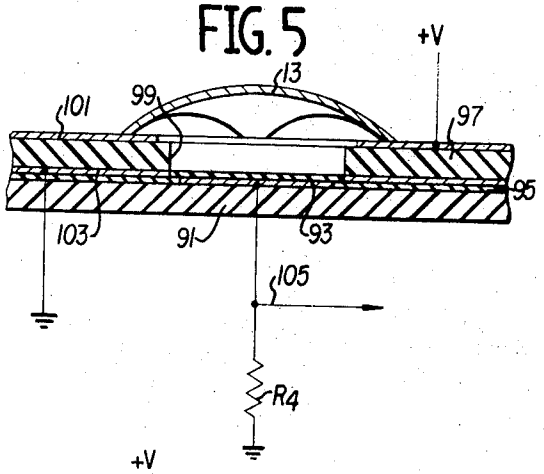


FIG.5



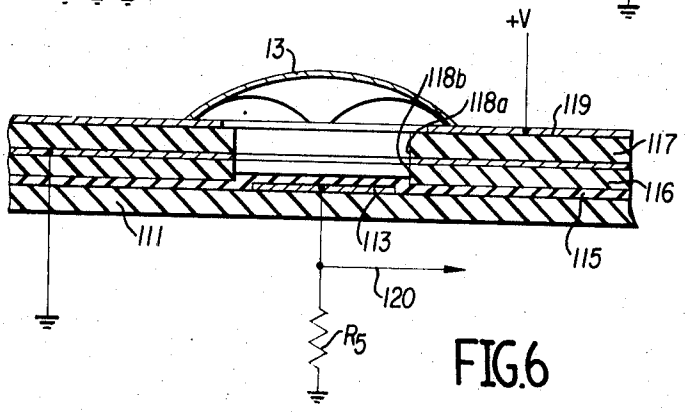


FIG.6

VARIABLE CAPACITOR

This is a continuation-in-part of commonly assigned U.S. Pat. application, Ser. No. 13,091, filed on Feb. 20, 1970, which issued on Mar. 28, 1972 as U.S. Pat. No. 3,653,038 and entitled "Capacitive Electric Signal Device and Keyboard Using Said Device." In accordance with a notice in Volume 859, page 346 of the Official Gazette dated Feb. 11, 1969, the subject matter of application, Ser. No. 13,091 is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The referenced application as well as this invention relate generally to impulse keys of an electrostatic or capacitive nature that are suitable for use in electronic keyboards or as separate switching elements. Reference is made to for a discussion of electronic keyboards and the various disadvantages of prior art impulse keys used therein.

While the electrostatic (capacitive) electric signal devices or impulse keys described in the referenced patent application have been found to be satisfactory in solving many of the disadvantages of prior art devices that perform the same function, there are certain areas still subject to improvement. For example, while they provide the desired output pulse under normal operating conditions, it has been found for at least one embodiment that resistive leakage at high humidity and temperature raise the signal electrode potential (i.e., the target potential) to a level higher than desirable.

Other structures generally made in accordance with the invention described in the referenced patent application, or slight modifications thereof, have been found to have other disadvantages. For example, in one structure surface leakage on the top side of the insulating film above the target brought the bias voltage onto the surface of the target thereby destroying the signal output. While various approaches have been proposed to solve the foregoing problems, they have not been entirely satisfactory in all environments. And, those that have been somewhat acceptable have been more complicated and, therefor, more expensive than desirable.

Therefore, it is an object of this invention to provide a new and improved electrostatic impulse key.

It is another object of this invention to provide a new and improved electrostatic impulse key suitable for use with electronic keyboards that operates over a wide range of humidity and temperature conditions without deterioration of the signal generated by the impulse key.

It is a still further object of this invention to provide new and improved electrostatic impulse keys wherein the bias voltage leakage path between the actuated element and the target is circumvented.

SUMMARY OF THE INVENTION

In accordance with principles of this invention, the basic key structure comprises a board or plate, which may be of a printed circuit board, on which one or more targets is formed. Located above the targets is a dome spring with preferably, three edges clipped so that the remainder essentially forms an equilateral triangle when viewed from above. Located above the dome depressable is a foam "spring" or pressure pad. Located above the foam spring is an actuator which is

depressable by the action of a key member attached thereto. When the key is pressed, the actuator moves against the foam. The foam transmits the force of the actuator to the top of the dome spring. When a sufficient force is applied the dome spring rapidly changes position. The dome spring rapid change in position rapidly changes the capacitance between the target and the dome spring. If the dome spring is connected to a source of DC power and the target or targets are connected through resistors to ground, a voltage pulse is generated across the resistors each time the key is depressed because of the capacitance change.

In accordance with further principles of this invention, a coil spring encompasses the foam and the dome spring between the target board and the actuator to preload the key so that a predetermined amount of pressure must be applied to the key prior to the foam causing the dome spring to rapidly change position.

In accordance with other principles of this invention, a printed circuit (target) board has the target or targets formed thereon and the remaining portion of the conductive surface of the board is removed. An insulating layer is then disposed on the target surface of the printed circuit board so as to cover the entire surface including the target area. Thereafter, a double-sided circuit board having an aperture located around the target area is located above the insulating layer. The top conducting layer of the double-sided printed circuit board supports the dome spring in an electrically contacting arrangement. The top conducting layer is connected to a predetermined voltage source so as to form a bias voltage plane. The lower conducting layer of the double-sided printed circuit board is connected to ground and forms a suitable ground plane. The targets are connected through suitable resistors to ground. This structural arrangement alleviates bias voltage-target leakage problems of prior art devices.

In the preferred form, the insulating layer is formed of a suitably doped glass epoxy film. In an alternate form, the insulating layer is formed of an imperfect insulating film which has been screened, dipped or sprayed to coat the surface.

In accordance with alternate principles of this invention, the target area comprises a first printed circuit board with a target region formed on its upper surface. The entire upper surface of the first printed circuit (target) board is covered by an imperfect insulating film. Thereafter, two single-sided printed circuit boards having apertures of approximately the size of the target region are mounted above the screened insulating film in parallel with their conducting surfaces being on the top of each board. The upper surface of the top of the two single-sided printed circuit boards supports the dome spring and is connected to a source of voltage. The conducting surface of the lower of the two single-sided printed circuit boards is connected to ground and the target region is connected through resistor(s) to ground.

It will be appreciated by those skilled in the art from the foregoing brief description that the invention provides an electrostatic impulse key suitable for use in an electronic key board or as an individual signal generating element. Because a spring is used to preload the actuator key, a positive action force must be applied prior to a signal being generated. However, when the positive

action force is applied a fast pulse is generated. Moreover, an audiable "click" can be heard. In addition, because a ground plane that essentially surrounds the dome spring and the target between these two items is included, the leakage problems of prior art devices are alleviated without the use of a complex system. Moreover, because the invention uses well known and readily available printed circuit boards, it is inexpensive to manufacture and construct.

BRIEF DESCRIPTION OF THE DRAWINGS

The foregoing objects and many of the attendant advantages of this invention will become more readily appreciated as the same becomes better understood by reference to the following detailed description when taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is an expanded view of a preferred embodiment of an electrostatic impulse key formed in accordance with the invention;

FIG. 2 is a cross-sectional view of an electrostatic switch of the type illustrated in FIG. 1;

FIG. 3 is a top view of an alternate form of a target suitable for use in the embodiment of the invention illustrated in FIG. 1;

FIG. 4 is a cross-sectional view illustrating in detail a printed circuit board sandwich arrangement suitable for use in the embodiment of the invention illustrated in FIG. 1;

FIG. 5 is an alternative cross-sectional view of a printed circuit board arrangement suitable for use in the embodiment of the invention illustrated in FIG. 1;

FIG. 6 is a further alternative cross-sectional view of a printed circuit board sandwich arrangement suitable for use in the embodiment of the invention illustrated in FIG. 1; and,

FIG. 7 is a top view of the dome spring portion of the invention and is used to illustrate the cross section of the spring dome shown in FIGS. 3–6.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A preferred embodiment of the overall impulse key structure of the invention is illustrated in FIGS. 1 and 2 and comprises: a target board 11; a dome spring 13; a cylinder of foam 15; a coil spring 17; a housing 19; an actuator 21; a lid 23; and a key 25.

The target board 11 is actually a sandwich of the type illustrated in FIGS. 4, 5 and 6, hereinafter described. The dome spring 13 lies above the target board and is a thin, dome-shaped metal spring, essentially the segment of a sphere about the size of a dime. Three edges of the sphere segment are clipped from the circle so that the remainder essentially forms an equilateral triangle when viewed from the top as shown in FIG. 7. A sufficient portion of the points of the triangle remain to provide contact with certain regions of the target board as hereinafter described. In a preferred embodiment the dome spring arches to a height of about 0.025 inches above the upper surface of the target board 11, when at rest.

Preferably the cylinder of foam 15 is formed of polyurethane and rests gently upon the top of the arched dome spring as illustrated in FIGS. 1 and 2. The coil spring 17 encompasses the cylinder of foam but is out of contact therewith. The coil spring also surrounds the dome spring and is out of physical contact therewith. In other words, the coil spring surrounds both the cylinder of foam and the dome spring and rests on the upper surface of the target board 11 as seen in FIG. 2.

The housing 19 is illustrated in FIGS. 1 and 2 as generally a cube, however, it may be of any suitable shape. The housing has four downwardly projecting legs 27 (only three of which are viewable in FIG. 1) located at the corners of the cube. The legs 27 pass through four aligned apertures 29 formed in the target board 11. Hence, when the housing 19 is arrayed atop the target board 11, the housing is located in a predetermined, fixed alignment above the target board. The housing includes a cylindrical aperture 31 in which the coil spring 17, the cylinder of foam 15 and the dome spring 13 reside. Located around the periphery of the cylindrical aperture 31 in vertical alignment are four semi-cylindrical recesses 33.

The actuator 21 is generally cylindrical in shape and includes four semi-cylindrical legs 35 (only three of which can be seen in FIG. 1) vertically arrayed along the outer surface thereof. The semi-cylindrical legs 35 fit into the semi-cylindrical recesses 33 formed in the housing 19. The actuator also includes an upwardly projecting cylinder 37 that includes an upwardly projecting X-shaped element 39. The lid 23 fits about the upwardly projecting cylinder 37 of the actuator 29 atop the housing 19, and includes a ring shaped portion 41 that surrounds the upwardly projecting cylinder. The remaining portion of the lid 23 is generally flat and includes four downwardly projecting legs 43 (only two of which are viewable in FIG. 1) that fit into four apertures 45 formed in the upper surface of the housing 19 about the cylindrical opening 31. The key 25 has a suitable aperture 38 (FIG. 2) formed in its bottom that tightly fits over the X-shaped element 39 formed atop the actuator 21 and is large enough to slide over the ring shaped portion 41 of the lid 23.

In operation, when the key 25 is depressed it forces the actuator 21 downwardly against the coil spring 17 and the cylinder of foam 15. When a sufficient amount of pressure is applied, the dome spring 13 rapidly collapses to change the separation distance between the dome spring and a target on the target board. This separation distance change changes the capacitance between these elements in a very rapid manner. In one actual embodiment the resulting capacitance increases to its maximum value in approximately 100 microseconds. Upon release of finger pressure on the key 25, the dome spring quickly recovers to its arched position over the target and the capacitance between the dome spring and the target rapidly returns its low value.

The coil spring does not impinge on the dome spring. Rather, as indicated above, the coil spring lies between the target board 11 outside of the target area and the actuator 21 and is merely provided to pre-bias the key so that a predetermined amount of force must be applied to the key prior to actuation of the dome spring, 25 grams of force, for example. The four semi-cylindrical legs 35 of the actuator which, as illustrated in FIG. 1, extend below the lower surface of the actuator maintain the coil spring in its desired alignment position.

As illustrated in FIG. 1, the invention may include three separated target rings 47, 48 and 49 concentrically arrayed on the target board 11. Any one of these rings will provide an output signal of the desired nature. Alternatively, as illustrated in FIG. 3, a solid ring segmented into three separated sections 51, 53, and 55 can be utilized. In either case, the target is surrounded by a further ring 57 on which the impinging portion of the spring dome resides. In addition, the target is not limited to three regions, rather the target can be a single target region, two target regions, or more than three target regions as desired.

It will be appreciated by those skilled in the art that one of the major problems with a structure of the type described above is leakage between the dome spring and ground and/or leakage between the targets and ground, depending upon which side of the "capacitor" is connected to the bias voltage source. The invention overcomes this problem by using one or the other of the target structures illustrated in FIGS. 4, 5 and 6 and hereinafter described. While the preferred target structure is illustrated in FIG. 4, the target structures illustrated in 5 and 6 also overcome the leakage problems of prior art electrostatic impulse keys of a similar nature.

The target structure illustrated in FIG. 4 comprises a printed circuit (target) board 61 having formed thereon a target 63 which may be a single target region or a plurality of target regions of the type heretofor described. However, for purposes of discussion FIG. 4 illustrates a target 63 formed of three target regions which may be rings of the type illustrated in FIG. 1. By any of several well known techniques, the target 63 is "layed out" on the upper conducting surface of the target printed circuit-board 61; thereafter, the remaining portion of the conductive surface is removed by any suitable process, such as by chemical etching, for example. Electrical connection to the three target rings is made by means of "plated thru" (conductive) holes which permit connection to the target rings to be made from the bottom side of the printed circuit board.

After the target printed circuit board has a target formed in its upper surface, a suitable thin and slightly imperfect insulating layer 65 such as, a doped glass epoxy film, or other screened, dipped or sprayed insulating material is formed over the entire upper surface of the target printed board 61, including the target 63. Following this formation, a double-sided printed circuit board 67 having an aperture 69 formed therein is arrayed atop the insulating layer 65. The aperture 69 is aligned directly over the target and has a cross-sectional area that is slightly larger than the area covered by the target 63. The upper conductive surface of the double-sided printed circuit board 67 is etched slightly rearwardly from the edges of the aperture 69. The dome spring 13 lies atop the upper conductive surface 71 of the double-sided printed circuit board 67 and is in electrical contact therewith. In addition, the upper conductive surface 71 is connected to a suitable DC bias voltage source +V and forms a voltage plane. The lower conductive surface 73 of the double-sided printed circuit board 67 is connected to ground and forms a ground plane. While FIG. 4 illustrates that the entire upper conductive surface 71 of the double-sided printed circuit board 67 is retained, only a portion thereof, such as a ring 57 as shown in FIGS. 1 and 3 need be retained, as desired.

In general, as somewhat previously described, when the dome spring 13 changes position, the capacitance between the dome spring and the target 63 changes. This capacitance change causes a voltage change across resistors R1, R2 and R3 connected between the target regions and ground. The voltage decreases are in the form of pulses which flow along three output lines 81, 83 and 85 connected respectively between R1, R2 and R3, and their respective target regions.

As a signal source, it will be appreciated, that the invention is in essence a "snap variable capacitor" and resembles a capacitor microphone, except that the signal voltage is much larger because of the comparatively extreme changing capacitance. For example, in one actual embodiment of the invention using a bias voltage of about 150 volts and a suitable target load resistance, a signal pulse of 15 to 20 volts was generated. The pulse duration was about one-half milli-second. While some ringing was found to occur, this was highly damped by the cylinder of foam 15.

FIG. 5 illustrates an alternate embodiment-of a target board formed in accordance with the invention which is somewhat similar to the target board illustrated in FIG. 4 but differs therefrom. For ease of illustration and description, only a single target region is illustrated in FIG. 5, however, a plurality of targets regions could be used in this embodiment, if desired.

The target board illustrated in FIG. 5 comprises a single-sided target printed circuit board 91 having a target 93 formed thereon. The target may be formed in any well known manner. However, in general, the target 93 is "layed out" on the conductive surface of the target printed circuit board 91. Thereafter, the remaining portion of the conductive surface is etched or removed in some other manner by any suitable process.

After the target 93 is formed, the entire upper surface of the printed circuit board 91 is covered with a suitable insulator layer. In the case of the embodiment of the invention illustrated in FIG. 5, an imperfect insulating material 95 is screened, dipped or sprayed to coat the upper surface of the target printed circuit board 91 with a suitable film.

After the insulating film 96 has been applied to the upper surface of the target printed circuit board 91, a double-sided printed circuit board 97 having an aperture 99 formed therein is arrayed over the insulating film 95 so that the aperture 99 is aligned over the target 93. Preferably, the cross-sectional area of the aperture 99 is slightly larger than the area covered by the target 93.

The upper conductive surface 101 of the double-sided printed circuit board 97 is etched slightly rearwardly from around the periphery of the aperture 99. Alternatively, if desired, only a ring around the aperture (set slightly back therefrom) could be left on the upper conductive surface. In any event, the remaining portion of the upper conductive surface 101 of the double-sided printed circuit board 97 supports the dome spring 13 and is connected to a voltage source +V and forms a voltage plane. The lower conductive surface 103 of the double-sided printed circuit board 97 is connected to ground and forms a ground plane. In addition, the target region 93 is connected through a re-

sistor R4 to ground. The output voltage is taken across R4 and passes along an output line **105**.

FIG. **6** is a further alternative embodiment of a target board formed in accordance with the invention and comprises a single-sided target printed circuit board **111** having a target **113** formed on its upper conductive surface in the manner generally described above. The upper surface of the target printed circuit board **111** is covered with an insulating film **115** such as an imperfect insulating film, for example. Thereafter, second and third single-sided printed circuit boards **116** and **117** are arrayed in parallel above the lossy screened insulating film **115** with their conducting surfaces being upwardly. The second and third printed single-sided circuit boards **116** and **117** each include an aperture **118***a* and **118***b* which align over the target region **113**. The apertures **118***a* and **118***b* have a cross-sectional area that is slightly larger than the area of the target **113**. In addition, the upper surface of the third single-sided printed circuit board **117** has its conductive area etched slightly rearwardly from its aperture **118***a*. The upper conductive surface **119** of the third single-sided printed circuit board supports the dome spring **13** and is connected to a voltage source designated +V to form a voltage plane. The conductive surface of the second single-sided printed circuit board **116** is connected to ground and forms a ground plane. In addition, the target **113** is connected through a resistor **R5** to ground. The voltage across **R5** is sensed on an output line **120**.

It will be appreciated from viewing FIGS. **4**, **5** and **6** that the invention can take on various structural forms. The forms are all related because each provides a ground plane that is physically located between the target area and the spring dome. The ground plane prevents leakage from destroying the signal generating capabilities of the invention. In addition, an insulating layer which is preferably a doped glass epoxy film but may be some other imperfect insulating film is located atop the target area, between the target area and the ground plane.

While the invention has been described as using conventional printed circuit boards which are normally copper clad on their conductive surfaces, preferably, the portion of the conductive surface on which the spring dome impinges is formed of a harder material, such as nickel, for example, that is more wear resistant. That is, as the spring dome is moved up and down as the key **25** is actuated wearing occurs between the legs of the dome spring **13** and the conductive surface on which it resides. Hence, it is desirable that this conductive surface be highly wear resistant. Consequently, it is preferred that a good electrically conductive material that is also highly wear resistant, such as nickel, be used in this region. This material may be plated or vacuum deposited over a conventional copper layer or applied in any other conventional manner, as desired.

It will be appreciated from the foregoing description that the invention provides a new and improved electrostatic impulse key that is suitable for widespread use. Because signal destroying leakage between the dome spring and the target area is prevented, the invention is suitable for widespread use, even in environments where temperature and humidity are high.

While the preferred embodiments of the invention have been herein described, it will be appreciated by those skilled in the art and others that various changes can be made therein without departing from the spirit and scope of the invention. Hence, the invention can be practiced otherwise than as specifically described herein.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. An electrostatic impulse key comprising:

a target board including an electrically conductive target and an electrically conductive ground plane surrounding said target and separated therefrom;

a curved spring mounted on the other side of said electrically conductive ground plane from said target in a manner such that the distance between said curved spring and said target can be abruptly decreased when pressure is applied to the upper surface of said curved spring; and,

key means for applying pressure to the upper surface of said curved spring to abruptly decrease the distance between said curved spring and said target when force is applied to said key means.

2. An electrostatic impulse key as claimed in claim **1** wherein said target board comprises:

a single-sided printed circuit board having said target formed in the conductive surface thereof;

an insulating layer covering the surface of said single-sided printed circuit board in which said target is formed, including covering said target; and,

a printed circuit board structure having two separated conductive layers, said printed circuit board structure being aligned over said single-sided printed circuit board and including an aperture aligned over said target, said curved spring being mounted on the conductive surface of said printed circuit board structure most remote from said target and the other conductive surface of said printed circuit board structure forming said electrically conductive ground plane surrounding said target.

3. An electrostatic impulse key as claimed in claim **2** wherein said insulating layer is a doped glass epoxy film.

4. An electrostatic impulse key as claimed in claim **2** wherein said insulating layer is an imperfect insulating film.

5. An electrostatic impulse key as claimed in claim **2** wherein the conductive surface of said printed circuit board structure that supports said curved spring is highly wear resistant.

6. An electrostatic impulse key as claimed in claim **5** wherein said wear resistant material is nickel.

7. An electrostatic impulse key as claimed in claim **2** wherein said printed circuit board structure is a double-sided printed circuit board.

8. An electrostatic impulse key as claimed in claim **2** wherein said printed circuit board comprises two single-sided printed circuit boards arrayed in parallel on said insulating layer with their conductive surfaces remote from said insulating layer.

9. An electrostatic impulse key as claimed in claim **1** wherein said key means comprises:

a depressable key;

an actuator attached to said key; and,

a cylinder of foam mounted between said actuator and the upper surface of said curved spring for transferring force applied to said depressable key to said curved spring.

10. An electrostatic impulse key as claimed in claim 9 including a housing mounted about said cylinder of foam and said actuator, said housing including a cylindrical opening aligned with said cylinder of foam, said cylindrical opening having a plurality of semi-circular recesses longitudinally formed in the outer surface thereof; said actuator including a plurality of semi-cylindrical legs which fit into the semi-cylindrical recesses in said housing so as to maintain said actuator in a predetermined alignment.

11. An electrostatic impulse key as claimed in claim 10 including a coil spring, said coil spring encompassing said cylinder of foam yet being out of contact therewith, said coil spring being mounted between said target board and said actuator so that a predetermined amount of force must be applied by said depressable key to said actuator prior to said curved spring changing position.

12. An electrostatic impulse key as claimed in claim 11 wherein said target board comprises:

a printed circuit board having said target formed in the conductive surface thereof;

an insulating layer covering the surface of said printed circuit board in which said target is formed, including covering said target; and,

a printed circuit board structure having two separated conductive layers, said printed circuit board structure being aligned over said printed circuit board and including an aperture aligned over said target, said curved spring being mounted on the conductive surface of said printed circuit board structure most remote from said target and the other conductive surface of said printed circuit board structure forming said electrically conductive ground plane surrounding said target.

13. An electrostatic impulse key as claimed in claim 1 wherein said curved spring is dome-shaped.

14. An electrostatic impulse key as claimed in claim 13 wherein the edges of said dome-shaped spring are clipped to form an equilateral triangle supported at its corners.

15. A target board suitable for use in an electrostatic impulse key wherein a key applies pressure to a dome spring to vary the distance and, thereby, the capacitance between the dome spring and an electrically conductive target, said target board comprising:

a target printed circuit board having a target formed of electrically conductive material;

an insulating layer covering the surface of said target printed circuit board in which said target is formed, including covering said target; and,

a printed circuit board structure having two separated conductive layers, said printed circuit board structure being aligned over said target printed circuit board and including an aperture aligned over said target, one of said conductive layers of said printed circuit board structure located to support said dome spring and the other conductive layer of said printed circuit board structure forming an electrically conductive ground plane that surrounds said target.

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