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Gillette et al.

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[54] **CROSSPOINT SWITCH UTILIZING ELECTRICALLY CONDUCTING LIQUID**

[75] Inventors: **Dean Gillette**, Rumson; **Ivan Pelech**, Morris Plains, both of N.J.

[73] Assignee: **Bell Telephone Laboratories, Incorporated**, Murray Hill, N.J.

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[21] Appl. No.: **297,498**

[52] **U.S. Cl.** **335/47**, 200/182, 337/49

[51] **Int. Cl.** **H01h 29/04**

[58] **Field of Search** 335/47, 48, 49, 50, 335/51, 52, 55, 57, 133, 112; 200/182, 183

[56] **References Cited**

UNITED STATES PATENTS

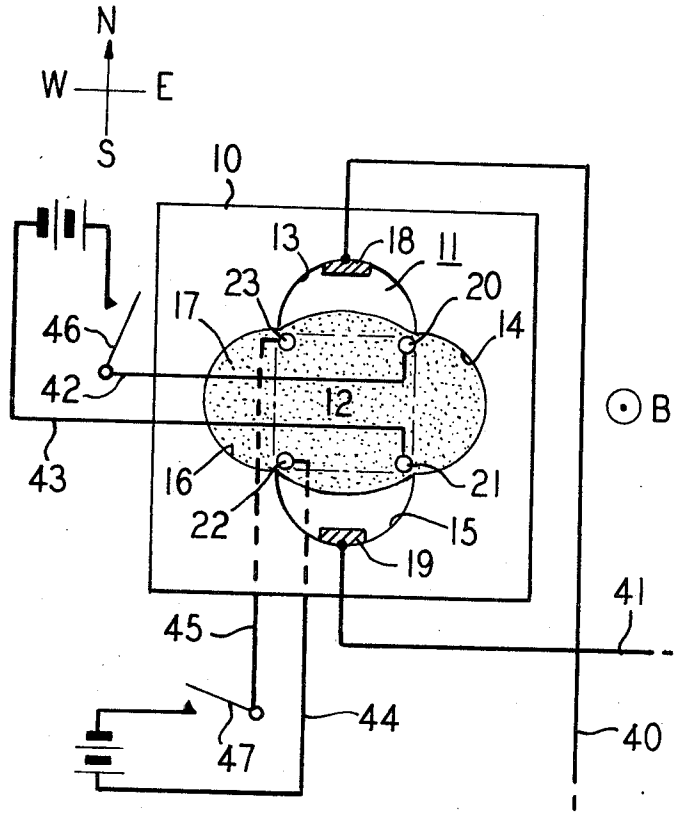
2,844,688	7/1958	Pfann	335/56
3,381,248	4/1968	Furth	200/182
3,699,485	10/1972	Lindenmeyer	335/49

Primary Examiner—Harold Broome
Attorney—W. L. Keefauver

[57] **ABSTRACT**

A crosspoint switch includes a housing defining an internal chamber having a central area communicating with four lobes equally spaced thereabout to form a clover-leaf configuration, and a droplet of electrically conductive non-magnetic liquid which can assume either of two stable positions within the chamber. These positions include the central area and opposite lobes in the North-South or East-West directions. When switched from one stable position to the other, the droplet makes or breaks an electrical connection between one or more pairs of signal leads disposed within the chamber. Switching is accomplished by biasing the entire chamber in a magnetic field perpendicular to its plane and by simultaneously applying compressive or tensile forces to the droplet by passing electric currents therethrough via two pairs of activating contacts within the chamber.

11 Claims, 7 Drawing Figures



2 Sheets-Sheet 1

FIG. 1

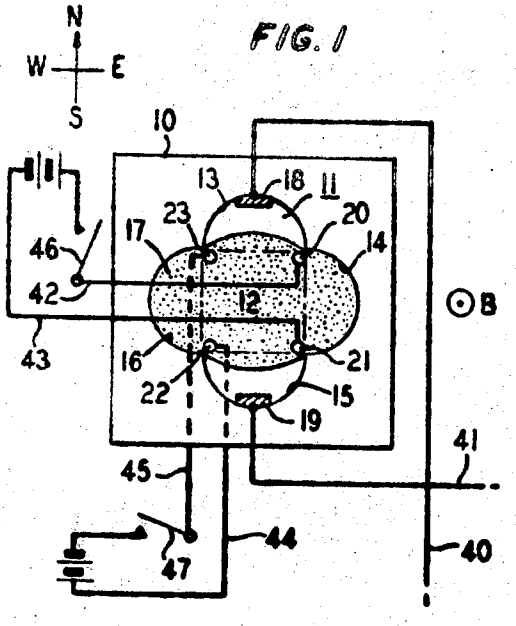


FIG. 2

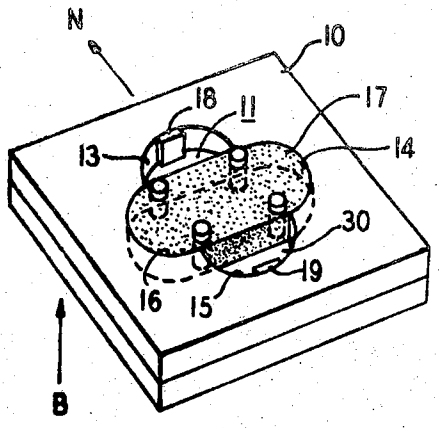


FIG. 3A

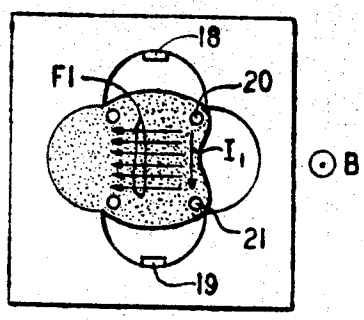


FIG. 3B

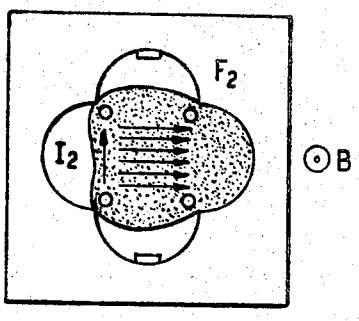


FIG. 3C

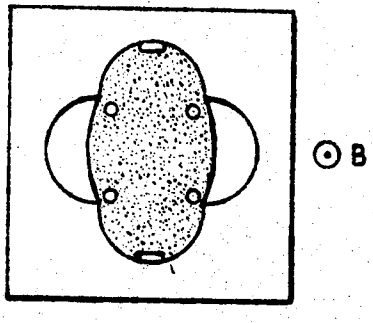


FIG. 3D

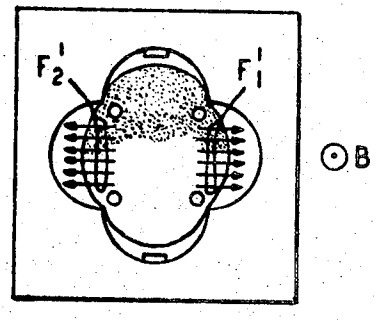
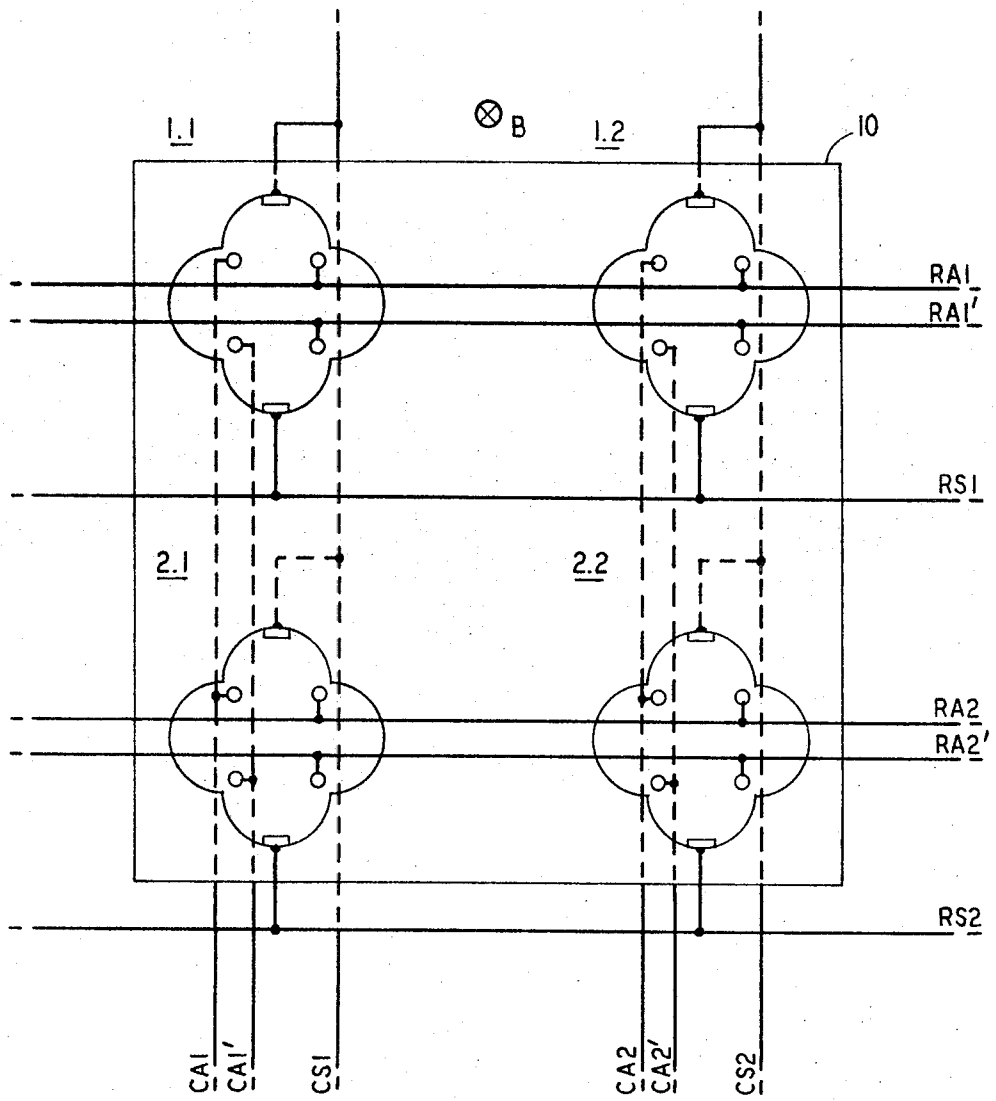


FIG. 4



CROSSPOINT SWITCH UTILIZING ELECTRICALLY CONDUCTING LIQUID

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates generally to crosspoint switches utilized to establish an electrical connection between a pair of signal leads in the presence of two simultaneous activating inputs, and, more particularly, to such a switch in which an electrically conducting liquid is manipulated to make the connection.

2. Description of the Prior Art

Various switches have evolved over the past several years which utilize the movement of an electrically conductive liquid, such as mercury, to establish an electrical connection between a pair of signal leads. These switches use many different means to accomplish the movement of mercury, including (1) changing the physical orientation of the switch to produce gravitationally induced motion, (2) rendering the liquid magnetic by incorporating therein particles of iron and directly applying an external magnetic force, and (3) utilizing air pressure, directly or indirectly, to move the mercury to a desired position. Very often, however, these methods have been found to be cumbersome and expensive to implement.

An additional method of switch actuation, which has proved to be quite advantageous, in comparison to the foregoing, is disclosed in U. S. Pat. No. 2,844,688, issued to W. G. Pfann et al. on July 22, 1958. In the Pfann switch, a magnetic biasing field is established and an electric current is passed between a pair of electrodes located within the mercury, so as to produce a motive force in the desired direction.

While the Pfann switch thus utilizes an improved method of mercury movement, it, as well as the several other switches of a similar nature well known in the art, are beset by problems of a slightly different nature, which result from the fact that each of these designs relies upon the essentially complete displacement of mercury from one position to another in order to accomplish the switching function. This displacement of mercury requires a relatively long time interval, which is dependent upon the mass of the globule, the motive force applied thereto, and the necessary travel of the moving surface. Also, depending upon the configuration of the switch chamber, gross movement of the globule often results in its fragmentation, or spray formation, upon reaching the distant position and before coming to rest.

In addition to the foregoing description, prior art switches of the type described are also generally incapable of providing the AND gate function required in a crosspoint switch, without the need for complex chamber designs or external logic circuitry. Numerous ones of these switches, indeed, require the provision of elaborate means simply to enable a latching action in either the ON or OFF state.

Accordingly, the broad object of the present invention is to improve the operational characteristics of a crosspoint switch utilizing a droplet of conductive liquid manipulated by motive forces generated by magnetic field-electric current interaction.

An additional object is the design of a crosspoint switch of the type indicated wherein problems associated with gross mercury movement are obviated by a switch housing which permits manipulation between

two distinct stable states without changing the center of gravity of the droplet, thereby enabling attainment of faster switching intervals and eliminating problems associated with droplet breakup and fragmentation.

Other objects of the instant invention are to achieve, in a mercury switch of the type indicated, a stable latching action in either the ON or OFF states, without unduly complicating the switch structure, and to include the AND gate function required in a crosspoint directly in the switch design.

SUMMARY OF THE INVENTION

Each of the foregoing and additional objects are achieved in accordance with the principles of the present invention by a crosspoint switch which includes a housing defining an internal chamber for containing a droplet of an electrically conductive liquid such as mercury, the chamber comprising a central region or area and four lobes equally spaced around its perimeter to form a clover-leaf shaped configuration. By virtue of this arrangement, the droplet can assume a stable position within the chamber in either the North-South or East-West directions, each position thus including the central area and one pair of oppositely spaced lobes. Switching from one stable position to the other is accomplished by biasing the chamber in a perpendicular magnetic field, and by simultaneously applying compressive or tensile forces to the droplet generated by the passage of two appropriate actuating currents therethrough. When switched, the droplet makes or breaks an electrical connection between one or more pairs of signal leads disposed within the chamber.

By virtue of the above-described chamber design, manipulation of the droplet between its two stable states advantageously requires no shift of its center of gravity. Accordingly, switching speed is considerably enhanced, in comparison with prior art apparatus, due principally to the shorter travel of the moving surface. In addition, problems associated with gross movement of the droplet are avoided, since the droplet is simply "deformed" during the switching operation. Because the dumbell-like cavity formed by oppositely spaced lobes and the central area of the chamber, and occupied by the droplet when at rest, is a configuration easily assumed and maintained by the mercury, a latching action is conveniently built into the switch. In addition, since two simultaneous actuating currents are required to effectuate switching from one stable state to the other, the AND gate function of a crosspoint is expediently provided.

BRIEF DESCRIPTION OF THE DRAWING

The aforementioned and other features and advantages of the instant invention will become more readily apparent to persons skilled in the art by reference to the following detailed description, when read in light of the accompanying drawing, in which:

FIG. 1 illustrates schematically a crosspoint switch constructed in accordance with the principles of the instant invention, in one of its stable states;

FIG. 2 is a view in perspective of the switch of FIG. 1;

FIGS. 3*a*, 3*b*, 3*c* and 3*d* are views similar to FIG. 1 showing a switching progression from the first stable state to the second, and vice versa; and

FIG. 4 illustrates schematically a four unit crosspoint array in accordance with the invention comprising four

interconnected switches similar to the switch of FIG. 1.

DETAILED DESCRIPTION

Referring now to FIGS. 1 and 2, wherein like elements have like designations, there is shown a crosspoint switch constructed in accordance with the present invention. The switch includes a housing **10**, constructed of a suitable material having non-magnetic walls, such as plastic, glass or the like, which defines a clover-leaf shaped chamber designated generally at **11**. More precisely, chamber **11** includes a central region or area **12**, indicated by dashed lines, which is approximately square in shape, four generally semi-circular lobes **13**, **14**, **15** and **16** which are equally spaced around the perimeter of area **12** and communicate directly therewith, and a bottom wall **30**. For ease of reference, the location of lobes **13**, **14**, **15** and **16** will hereinafter be referred to as North, East, South and West, respectively, in relation to area **12**, as indicated in FIGS. **1** and **2**.

Contained within chamber **11** is a globule or droplet **17** of an electrically conductive liquid, such as mercury, in an amount sufficient to fill area **12** and lobes **14** and **16**, but insufficient to occupy the entire chamber. As shown in FIG. **1**, a small portion of droplet **17**, when at rest in the East-West direction, does extend into lobes **13** and **14**, due to surface tension effects. However, the liquid is not, in this position, in contact with signal contacts **18** and **19**, which are disposed within the outermost portions of lobes **13** and **15**, respectively.

Switching of droplet **17** from the position shown in FIGS. **1** and **2** to the North-South position shown in FIG. 3c is accomplished as follows: First, a magnetic biasing field, in a direction essentially perpendicular to the plane of chamber **11**, is established by means of one or more permanent or electromagnets, not shown, positioned in the vicinity of housing **10**. This field is designated by upward vector B in FIGS. **1–4**, but, of course, a field of opposite polarity could also be applied. Second, electric currents of proper polarity are passed through droplet **17** by means of actuating terminals **20**, **21**, **22** and **23**, which are positioned within area **12** of chamber **11**. These currents interact with the magnetic biasing field to produce forces, on droplet **17**, whose orientation follows the well-known "right hand rule." As will be explained more fully hereinafter, these forces are advantageously arranged to distort droplet **17** from its position in FIGS. **1** and **2** to the position depicted in FIG. 3*c*, at which time an electrical connection is completed, by the liquid, between signal contacts **18** and **19**.

To better understand the switching operation, reference may now be made to FIGS. 3*a*, 3*b* and 3*c*, which indicate the progression of droplet **17** from the East-West to the North-South directions. Specifically, if a current represented by vector I_1 is passed through droplet **17** by impressing a positive direct voltage on actuating terminal **20** with respect to actuating terminal **21**, the droplet is deformed under the influence of electromagnetic forces represented by vectors F_1 to the position shown in FIG. 3*a*. This position, which does not provide an electrical connection between signal contacts **18** and **19**, is an unstable one, due to surface tension effects on the droplet, so that, when the single activating current I_1 is removed, the droplet reassumes the stable position of FIGS. **1** and **2**. In a similar manner, the passage of a current, designated I_2, from activating contact **22** to activating contact **23** produces a droplet deformation to the configuration of FIG. 3*b*, under the influence of electromagnetic forces F_2. Again, when the current I_2 is removed, droplet **17** returns to its initial East-West position.

As should be evident from an analysis of both FIG. 3*a* and FIG. 3*b*, the simultaneous application of currents I_1 and I_2 compresses the end portions of droplet **17**, which is thus forced to occupy the empty area of lobes **13** and **15**, as shown in FIG. 3*c*. Since this North-South position is a stable one, as previously discussed, droplet **17** remains in this state even upon removal of the activating currents.

Switching of the droplet from the North-South to East-West positions is accomplished in a manner analogous to that just described. In this case, the polarity of currents I_1 and I_2 is simply reversed, so that tensile electromagnetic forces F_1' and F_2' are applied to droplet **17**, as shown in FIG. 3d. These forces are sufficient to draw the droplet, due to surface tension effects, out of lobes **13** and **15** into lobes **14** and **16**.

Before proceeding with a description of the application of the switch of FIGS. **1–3** as a crosspoint, it is instructive to note that various alternative arrangements of signal contacts are available, in addition to the one shown. For example, in certain applications it may be useful to employ an additional pair of signal contacts similar to contacts **18** and **19**, in lobes **14** and **16**. In this event, the following table indicates the state of each pair of signal contacts, for each stable position of globule **17**.

TABLE 1

Globule Position	Signal Contacts 18–19	Signal Contacts in lobes 14 & 16
North-South	Closed	Open
East-West	Open	Closed

In addition, it is to be noted that a pair of signal contacts, such as contacts **18** and **19**, could, if desired, be located within the same lobe, spaced apart in either the horizontal or vertical directions. If vertically spaced, signal current passed between the contacts travels in a direction parallel to the magnetic biasing field, so that no undesirable electromagnetic forces are generated. However, even in the case of horizontal spacing, the signal current, whether DC or AC, in most applications, is not of sufficient magnitude to create a motive force that could distort droplet **17** from one stable state to the other.

The switches of FIGS. **1** and **2**, which are capable of many diverse applications in the electronics industry, may be referred to as single wire crosspoint. By single wire, it is understood that one signal contact, such as contact **18**, is connected to a column signal lead **40**, while another signal contact, such as contact **19**, is connected to a row signal lead **41**. In this configuration, activating contacts **20** and **21** are connected to row activating leads **42** and **43**, respectively, and activating contacts **22** and **23** are connected to column activating leads **44** and **45**, respectively. Assuming that droplet **17** is initially in the stable East-West position, it will be apparent from the foregoing that simultaneous application of positive voltages on activating leads **42** and **44** with respect to activating leads **43** and **45**, by closing switches **46** and **47**, will cause deformation of droplet **17** to the stable North-South position, thereby provid-

ing an electrical connection at the crosspoint formed by signal leads **40** and **41**. The AND gate function of the crosspoint is provided by the novel switch design, which requires simultaneous actuation on both row and column activating leads to deform the conductive liquid. The connection thus established will remain until the droplet is again deformed by the simultaneous application of actuating voltages on both pairs of activating leads of a polarity opposite to that shown in FIG. **1**.

Referring now to FIG. **4**, there is shown an arrangement of four switches similar to the switch of FIG. **1**, interconnected to form a crosspoint array or matrix. For ease of identification, the following prefixes are used to identify the various leads shown, solid lines indicating row wiring above housing **10** and dashed lines indicating column wiring below the housing:

Row activating lead	RA
Column activating lead	CA
Row signal lead	RS
Column signal	CS

The four switches are designated generally as **1.1, 1.2, 2.1, 2.2**, to indicate their positions in the 2X2 matrix, the first digit denoting row location and the second digit denoting column location, in accordance with standard practice. The switches may be fabricated in a single housing **60**, of suitable material, or may consist of four individual units of the type shown in FIGS. **1** and **2**.

As shown in FIG. **4**, one pair of activating terminals of each switch in the first row is connected, in parallel, to activating leads RA1 and RA1′, and similarly, one pair of activating terminals of each switch in the second row is connected in parallel, to activating leads RA2 and RA2′. The remaining pairs of activating terminals of each switch in the first and second columns are likewise connected in parallel to leads CA1—CA1′ and CA2—CA2′, respectively. One signal terminal of each switch in the first row is connected to signal lead RS1, and similarly, one signal terminal of each switch in the second row is connected to signal lead RS2. The remaining signal terminals of each switch in the first and second columns are likewise connected to signal leads CS1 and CS2, respectively.

In the configuration shown, it is possible to establish (or break) an electrical connection between any row signal lead and any column signal lead, or, stated differently, to close (or open) any crosspoint in the switch matrix. For example, if a connection (disconnection) between RS1 and CS2 is desired, appropriate voltages are applied to RA1-RA1′ and CA2-CA2′. Since both pairs of activating contacts in switch **1.2** are thus energized, the droplet contained therein is deformed from one stable state to the other, and the desired result effectuated. At the same time, only one pair of activating terminals in switches **1.1** and **2.2** are energized, so that the droplets contained therein are not sufficiently deformed to assume a new stable position. In a similar manner, other crosspoints may be controlled by properly energizing row and column activating leads, as follows:

TABLE 2

Switch to be Controlled	Signal Leads Affected	Row Activating Leads to be Energized	Column Activating Leads to be Energized
1.1	RS1&CS1	RA1–RA1′	CA1–CA1′
2.1	RS2&CS1	RA2–RA2′	CA1– CA1′
2.2	RS2&CS2	RA2–RA2′	CA2–CA2′

From the foregoing, it should be apparent that the matrix of FIG. **4** may be expanded to any number of crosspoints in a square configuration or otherwise, and that the state of any crosspoint may be conveniently changed without affecting the state of the other crosspoints in the array. It is also to be noted that the actuating and signal leads of the matrix are particulary well suited for fabrication in printed circuit form, since row and column wiring is confined to the surfaces above and below the switch housing, respectively, and crossovers are thus not required.

To obtain an appreciation of the small size of a crosspoint switch constructed in accordance with the principles of the invention, and to illustrate its speed and efficiency, the following parameters are given, by way of illustration only:

TABLE 3

Diameter of chamber at widest point	0.125″
Depth of Chamber	0.030″
Volume of Conductive Liquid	4.0 μl
Activating Current Pulses	100 msec at 5 amps
Transition Speed	20 msec
Magnetic Field Strength	0.22 W/m²

Many modifications and adaptations of this invention will readily become apparent to those skilled in the art. For this reason, it is intended that the invention be limited only by the appended claims. For example, bottom wall **30** of chamber **11** may be formed from a slab of non-magnetic material separate from the slab defining area **12** and lobes **13–16**, and a top or cover may be placed over chamber **11** to prevent contamination of the conductive liquid. Also, the intersections of the lobes with central area **12** may be slightly rounded to enhance the smoothness of fluid flow during switching.

What is claimed is:

1. An electrical switch comprising

a housing defining an internal chamber having a central region and four lobes communicating with said region, said lobes having substantially equal angular spacings around the perimeter of said central region,

a globule of electrically conductive liquid disposed within said chamber and assuming a first stable position extending from said central region into a first pair of opposite ones of said lobes,

means for deforming said globule from said first stable position to a second stable position extending from said central region into the remaining pair of opposite ones of said lobes, and

means within said chamber for effecting electrical switching in response to said deformation.

2. The invention defined in claim **1** wherein said means for effecting switching includes first and second signal leads disposed within opposite ones of said lobes.

3. The invention defined in claim **2** wherein said deforming means includes

means for biasing said chamber in a magnetic field substantially perpendicular thereto, and

means for simultaneously passing two currents through portions of said globule in opposite directions, thereby generating electromotive forces thereon.

4. The invention defined in claim **3** wherein said means for passing current includes first and second

pairs of activating electrodes positioned within said chamber in said central region.

5. The invention defined in claim 4 wherein said central region is generally square and said lobes are each generally semi-circular.

6. A crosspoint switch comprising

a housing defining an internal chamber having a generally square central area and four generally semicircular lobes communicating with said central area and spaced substantially equally around the perimeter thereof,

a droplet of mercury disposed within said chamber and capable of assuming a first or a second stable position within said chamber, said first stable position including said central area and a first pair of oppositely spaced ones of said lobes and said second position including said central area and the remaining pair of oppositely spaced ones of said lobes,

first and second signal contacts disposed within said chamber, and arranged to contact said droplet in said second stable position, and

means for switching said droplet from said first to said second stable position, thereby establishing an electrical connection between said signal contacts.

7. The invention defined in claim 6 wherein said switching means includes

means for biasing said chamber in a perpendicular magnetic field, and

means for simultaneously passing two activating currents through said droplet thereby generating electromotive forces thereon.

8. The invention defined in claim 7 wherein said first and second signal contacts are disposed within one of said lobes and vertically spaced one from the other.

9. The invention defined in claim 7 wherein said first and second signal contacts are disposed within opposite ones of said lobes.

10. A crosspoint matrix comprising

a plurality of interconnected electrical switches arranged in *m* rows and *n* columns, each including

1. a housing defining an internal chamber having a substantially square central area and four generally semicircular lobes communicating with said central area and spaced equally around the perimeter thereof,

2. a droplet of non-magnetic electrically conductive liquid contained within said chamber and arranged to assume a first stable position in said chamber including said central area and one pair of opposite ones of said lobes,

3. first and second signal contacts disposed within said chamber in the remaining pair of opposite ones of said lobes,

4. means for biasing said chamber in a perpendicular magnetic field, and

5. first and second pairs of activating contacts within said chamber arranged to pass electrical currents through said droplet, thereby generating electromotive forces on said droplet for switching said droplet from said first stable position to a second stable position including said central area and the remaining part of opposite ones of said lobes, wherein

a. each of said first pairs of activating contacts of said switches in each of said *m* rows is interconnected in parallel to *m* pairs of row activating leads,

b. each of said second pairs of activating cuntacts of said switches in each of said *n* columns is interconnected in parallel to *n* pairs of column activating leads,

c. each of said first signal contacts of said switches in each of said *m* rows is connected to *m* row signal leads,

d. each of said second signal contacts of said switches in each of said *n* columns is connected to *n* column signal leads, whereby an electrical connection between one of said *m* rows signal leads and one of said *n* column signal leads is established by the simultaneous application of an activating current to the appropriate one of said *m* pairs of row activating leads and to the appropriate one of said *n* pairs of column activating leads.

11. The invention defined in claim 10 wherein said row activating leads and said row signal leads are disposed above said housing and said column activating leads and said column signal leads are disposed below said housing.

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