June 21, 1960 J. W. DIESEL 2,942,077

ELECTROSTATIC CONTROLS

Original Filed July 2, 1954 2 Sheets-Sheet 1

FIG. 1

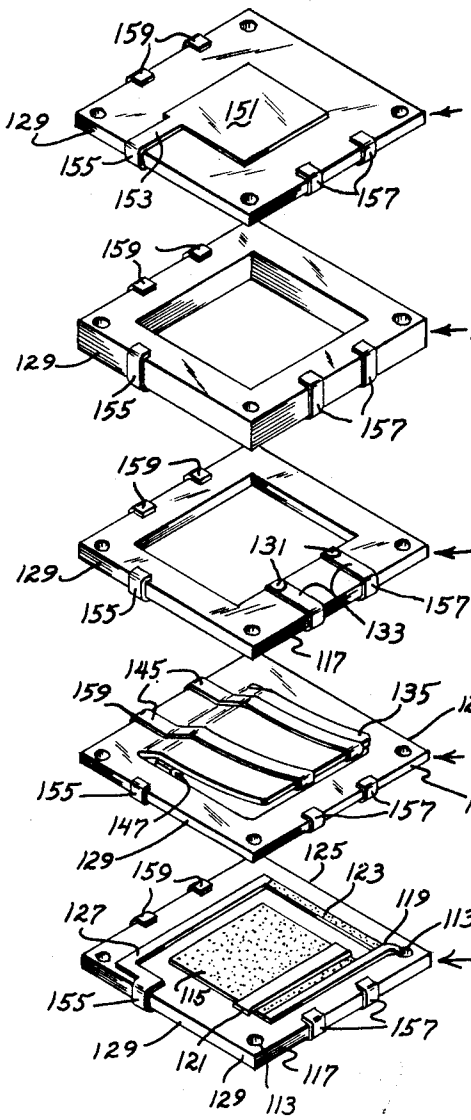

FIG. 2

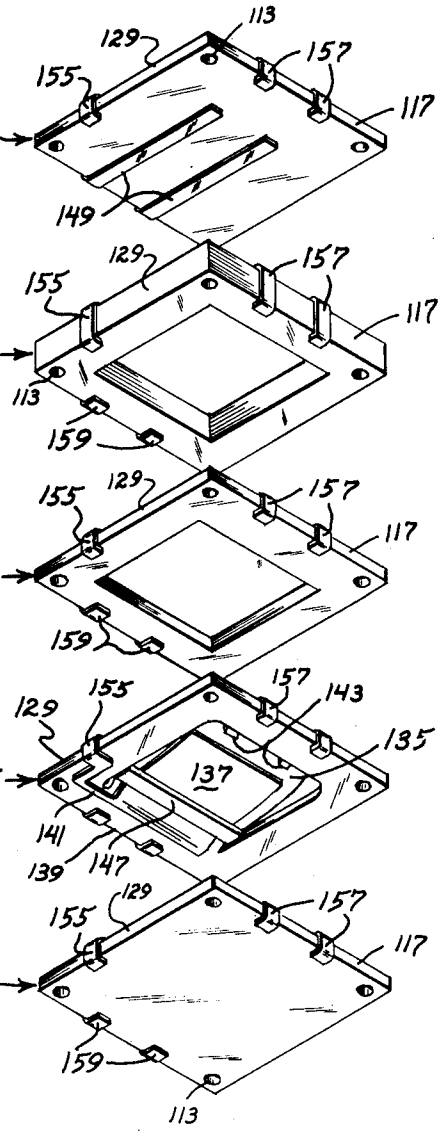

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FIG. 6

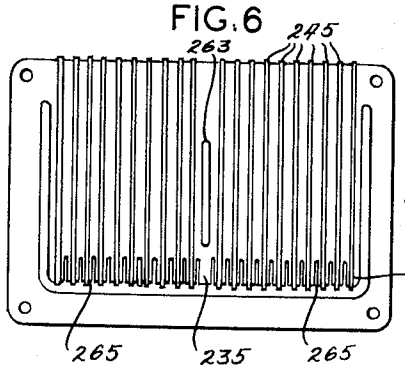


FIG. 7

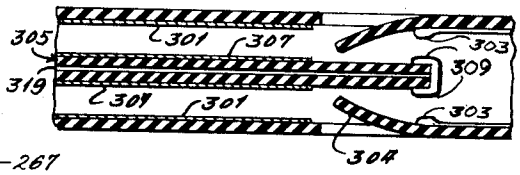


FIG. 3

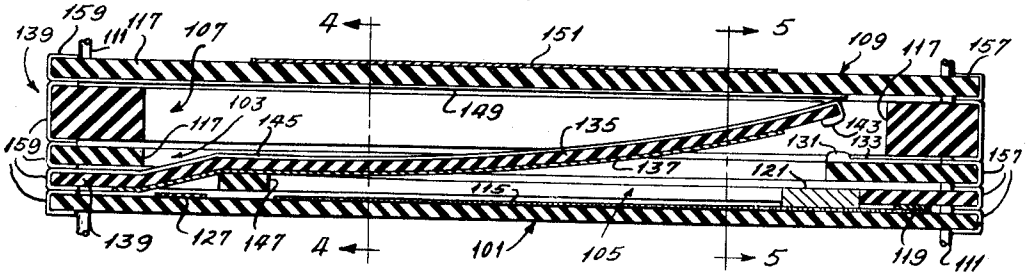


FIG. 4

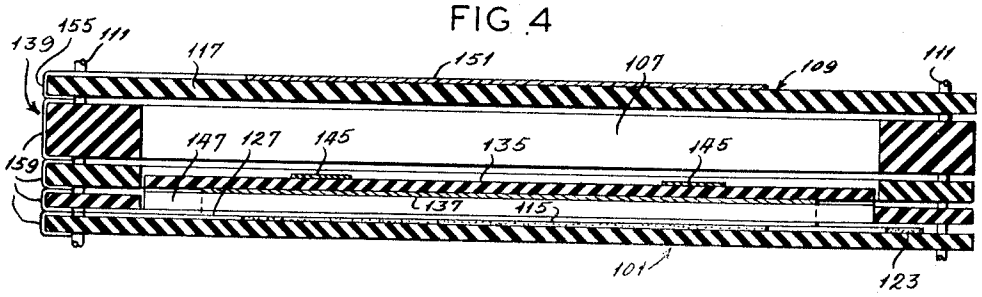
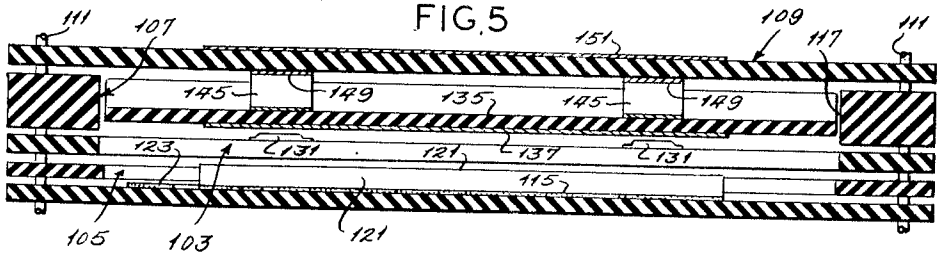


FIG. 5



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2,942,077

ELECTROSTATIC CONTROLS

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Original application July 2, 1954, Ser. No. 441,057. Divided and this application Oct. 28, 1957, Ser. No. 692,602

18 Claims. (Cl. 200—87)

This invention relates generally to electrostatics and more particularly to electrostatic controls, such as relays, and is a division of my copending application, Serial No. 441,057, filed July 2, 1954.

It has been known for many years that an attractive force is developed between two bodies when they bear opposite electric charges, but the commercial applications of this principle have been few. Indeed, the electrostatic controls heretofore proposed have been largely laboratory curiosities of erratic performance and considerable complexity. Accordingly, it is an object of the invention to simplify the construction and improve the operation of electrostatic controls. More specifically, the invention provides electrostatic controls that are comparable in function to electromagnetic and electronic devices, but which can be operated with better efficiency, manufactured at substantially less cost, made considerably more compact, and more conveniently connected and assembled in multiple-component apparatus.

The construction of an electrostatic relay has presented serious problems to those skilled in the art. The electrostatic or actuating forces are quite weak and are extremely sensitive to plate spacing, with the result that the performance is erratic and considerable precision is required in manufacture. If the plate spacing were slightly greater than intended, the plates would fail to attract, and if too close, they would readily be actuated by extraneous secondary effects, such as might result from leakage.

Attempts to resolve these difficulties by the use of high voltage and close spacing of the plates have not been too successful, because they lead to a considerable problem in preventing discharge between the plates, such discharge resulting in loss of the electrostatic force. It has, therefore, been suggested that the plates be protected against discharge with an intervening layer of solid insulation, but this expedient has led to even more serious difficulties. The introduction of solid insulation necessitates an increase in the distance between the conductive surfaces of the plates, which consequently weakens the electrostatic force, and the insulation, if not of considerable thickness, is subject to breakdown under high voltage stresses. More important, however, are the problems that arise from dielectric absorption and the property of the insulation to collect a surface charge, these factors causing the plates to stick and otherwise misbehave. In some instances, the plates will fail to release upon removal of the exciting voltage, and in other instances, the plates will move in a direction opposite to that intended when excitation is applied.

Accordingly, one of the objects of the present invention is to provide an improved relay structure especially adapted for multi-component apparatus. With such a relay, closed or open circuit conditions are determined more by the distance between the contacts rather than by actual engagement, and the behavior is more analogous to that of a gas-filled tube than that of a solenoid relay. Such high voltages (which in the case of a multi-component apparatus would be of the same order of magnitude as those used to excite the plates) permit the establishment of a closed circuit condition, even though the contacts are not in perfect engagement, a feature which greatly facilitates manufacturing procedures and improves reliability. Low current signals are desired, especially when the contacts are small, in order to prevent heating to an extent such that an injurious arc effect is established by burning, melting or vaporization of the contacts. High-voltage low-current signals have additional advantages when the circuit components are formed by printed circuit techniques.

One of the fundamental concepts of this invention is the use of high voltage and close spacing of the plates, features which have heretofore been impractical, but for the introduction of a solid intervening insulator for preventing discharge between the plates, which insulator, in turn, has resulted in additional difficulties of an even more serious nature. The invention contemplates, in a preferred embodiment, that there will be no such solid insulator, but that neutralizing discharge between the plates will be controlled by high resistance within the control itself. Preferably, one of the plates is formed, at least in part, of high resistance material, and discharge is localized over certain areas of the plates, the arrangement being such that other areas of the plates will be maintained at different potential, despite the presence of a charge transfer. This arrangement serves to prevent the uncontrolled accumulation of charges of a type that would produce malfunctioning of the control, and also permits very close spacing of the plates.

Additionally, the invention contemplates the provision of a high resistance shorting connection between the plates, the arrangement being such as to permit adequate accumulation of charges on the plates in response to plate excitation and yet quick removal of such charges in response to the withdrawal of the exciting voltage. This shorting connection or release circuit has the additional function of discriminating between true exciting signals and extraneous charges resulting from leakage, which if permitted to accumulate, might result in false actuation of the control.

While the above principles might be utilized in a wide variety of structures of differing application, the invention further provides an improved relay structure especially adapted for multi-component apparatus. Briefly, such a relay comprises a plurality of overlying panels of insulating material, upon which panels the plates, circuit parameters and leads are formed as conductive coatings by printed circuit techniques. One of the panels may be a relatively fixed rigid member, whereas an opposite panel may be mounted to flex toward and away from the fixed panel in response to the presence and absence of plate excitation. The plates are formed on opposed faces of these panels as areas of the order of a square inch, contacts being actuated by relative movement of the panels.

In one embodiment, the movable panel includes a flap, the free end of which is normally spaced from the fixed panel so that the inherent resilience thereof supplies the bias for opening the contacts and separating the plates. This flap is enclosed in a fixed frame-like spacer and is limited in outward movement by a fixed overlying shielding panel. A movable contact is secured at the free end of the flap for cooperation with a fixed contact mounted over the panel, a low-resistance plate being formed by silver paint on the flap and a high-resistance coating being formed on the other fixed panel with a carbon paint. With this arrangement, the free end portion of the movable plate is prevented from engaging the high-resistance fixed plate, although the plates may engage one another in their center portions. The exciting circuit lead for the high-resistance plate then extends therefrom adjacent the free end of the flap. Leads for the movable contact and

plate may extend on opposite faces of the flap to the fixed end thereof; and a high-resistance release circuit is provided for shorting the plates.

The terminals for the plates and contacts are brought out at the sides and ends of the unit; and these terminals may extend across the edges of the unit in order to make connection with similar units stacked one upon the other or with a suitable base upon which units are secured. It will be observed that this laminar panel construction simplifies manufacturing operations inasmuch as such panels may be readily die cut, printed and assembled with automatic machinery.

Other features of the invention will be in part apparent from and in part pointed out in the following detail description taken in connection with the accompanying drawings, in which:

Fig. 1 is an exploded view of certain insulating panels which are assembled to form a relay;

Fig. 2 is a view similar to that of Fig. 1, but showing the reversed faces of the insulating panels;

Fig. 3 is an enlarged sectional view of the assembled panels, thicknesses being exaggerated;

Fig. 4 is a sectional view taken on the line 4—4 of Fig. 3;

Fig. 5 is a similar section taken on the line 5—5 of Fig. 3;

Fig. 6 is a top plan view of a relay arm showing a construction for use where a relay is to control a large number of secondary circuits; and

Fig. 7 is a detailed sectional view illustrating an alternative embodiment of the relay arm.

Reference is now made to Figs. 1–5 for a description of a specific structure which might be used as a relay in a digital computer and other multi-component apparatus. The device comprises a plurality of flat, generally rectangular insulating members for carrying the conductive elements. In a device for controlling ten secondary circuits, the panels measure approximately three inches in width and length, and are of varying thickness and composition. A bottom panel **101** and top panel **109** are .010 inch Vinylite (polymerized vinyl chloride resin), a relay-arm panel **105** is .005 inch Vinylite, a contact member **103** is .020 inch Vinylite, and a spacer frame **107** is .060 inch laminated phenolic or styrene resin. Such insulating members would be die cut from sheet stock, the conductive elements being formed thereon using printed circuit techniques. The coated members are then assembled in stacked overlying relationship and are secured together, as by bolts **111** through corner apertures **113**.

The panel **101** constitutes the base of the device and serves as a support for the fixed plate, which is formed as a coating **115** of conductive paint. Conductive paints being known in the art, they are not described other than to note that they customarily comprise a suspension of conductive granules in a suitable binder. The resistance of the paint and resulting coating is to some extent controlled by the proportions and character of the ingredients, silver granules being generally used where high conductivity or low resistance is desired, and carbon granules being utilized for high resistance paint.

In the disclosed embodiment, the fixed plate **115** is formed as a high resistance coating measuring one and three-eighths inches in width and one and three-fourths inches in length. The paint is of a type providing approximately one hundred seventy-five megohms per square inch, this being a term of art indicating that a coating one inch in width and length normally has a resistance of the stated value between opposite edges. The plate area **115** extends close to an end **117** of the device and a high conductivity lead is formed as a strip **119** to extend across that end of the plate to an adjacent corner aperture **113**. A connection to ground and to the negative terminal of the exciting source is then made through the associated bolt **111**.

It may be observed at this point that the terms high resistance and high conductivity (or low resistance) are used in a relative sense inasmuch as printed leads formed with silver paint will have appreciable resistance. It is only intended that the voltage drop in the leads are nominal in relation to the drop at a resistive plate or across one of the resistances referred to. Also, a distinction is made between resistive material, such as carbon paint, and a semi-conductive dielectric, such as stone or organic membranes, the latter having only a very slight leakage usually aided by absorbed moisture. Semiconductive dielectrics are considered impractical because of their very high volume resistivity, if such materials can really be considered to have a resistance.

The plate **115** may in part extend beneath a thin piece **121** of insulating material, which is located at the end **117** of the device to minimize leakage between the fixed plate and fixed contacts. This covered portion of the plate **115** serves as a plate series resistance. The resistor of the release circuit (as disclosed in the parent application) is a relatively narrow strip **123** of high-resistance conductive paint extending over the panel **101** outwardly of the plate **115** and inwardly of the side edge **125** of the device, and a lead **127** extends therefrom to the side **129** of the device. The width and length of this strip, as well as the character of the paint, determine the resistance in the release circuit, which could be approximately thirty megohms in the described embodiment.

The contact member **103** has a central opening for accommodating the relay arm of the device, and upwardly-facing contacts **131** are mounted along the margin of this opening and high-conductivity leads **133** extend to the adjacent end **117** of the device. Although conductive paints may not be entirely satisfactory for contact purposes, there are other techniques known in the art which may be utilized in forming a lightweight contact which will withstand the slight heating to be expected from sparking. Although some degree of uniformity is desired when there are several contacts, the problem is not what it is in conventional devices where wiping engagement is generally necessary to establish a closed circuit condition and where contact "rebound" is a matter for concern.

The relay-arm panel **105** is cut about the margins **117**, **125** and **129** to form a resilient flap **135**, the free end of which extends over the fixed contacts **131** as a relay arm. The movable plate is a high-conductivity coating **137** over the lower face of the flap, the plate extending from a point short of the free end to the other end **139** of the device, where it is connected to a strip **141** of high-conductivity paint. The conductor **141** extends over the fixed marginal portion of the panel to the side **129**, so as ultimately to make a connection with the lead **127** of the release circuit.

Movable contacts **143** are mounted on the free end of the flap for cooperation with the fixed contacts, and lead-forming strips **145** of high-conductivity paint extend over the upper face of the flap to the end **139** of the device. Inasmuch as the flap is flexed during use, it may be desirable to incorporate a plasticizer in the conductive paint forming the coatings **137** and **145**.

In assembly, a narrow piece **147** of insulating material is sandwiched between the flap **135** and the bottom panel **101** adjacent the fixed or hinged end so as to urge the relay arm **135** upwardly. Movement of the relay arm is accommodated by the surrounding frame-like spacer **107** and is limited by engagement with the overlying top panel **109**. When several devices are to be stacked one upon the other, the panel **109** may be coated to shield the several devices against electrical interference with one another. Conductive strips **149** on the lower face of the panel **109** extend over the contact leads **145** and are electrically connected thereto at the end **139** of the device, whereas a conductive shield **151** on the upper face of this panel is connected to the movable plate by a lead **153** at the side **129** of the device.

It will be noted that the free end portion of the flap **135** is projected through the contact member **103** and is also curled outwardly somewhat, the latter being desirable in that it permits relatively close spacing of the plates **115** and **137** with rather wide spacing at the contacts. Contact closure is achieved both by downward movement of the flap and by a tendency of the flap to straighten under the electrostatic forces applied across the plates. The contact member **103** prevents the plates from coming into physical engagement over their entire surfaces, however. The inherent resiliency of the flap supplies the bias for otherwise opening the contacts and separating the plates, the wedging strip **147** being adjustable to vary the amount of bias, but in the finished device, this wedging strip is secured so that the device may be operated in any position.

The disclosed arrangement also provides for connection of the electrical elements merely by assembly of the panels. To that end, connecting elements of high-conductivity paint are formed on the several insulating members to extend across the edges thereof and partially over the margins. Connecting elements **155** provided at the side **129** are aligned so that the leads **127, 141,** and **153** become connected with one another when the members are assembled together. Connecting elements **157** are provided at the end **117** in alignment with the leads **133** for the fixed contacts. Similar connecting elements **159** located at the other end serve to connect the leads **145** for the movable contacts and the overlying coextensive shielding strips **149**. The arrangement is not only desirable in facilitating the construction of a single unit but also facilitates the assembly and connection of several units, whether they be stacked one upon the other or mounted on a panel previously ruled with conductive strips adapted to register with the connecting elements **155, 157** and **159**.

Fig. 6 illustrates an alternative arrangement which might be used where a rather wide relay arm is required to accommodate a large number of secondary circuits **245**. In this instance, one or more slots **263** are cut in the center of the flap **235** to relieve buckling and facilitate escape of the air cushion between the plates as the relay arm is actuated. While there are no theoretical limits to the size of the relay arm, present experience seems to indicate that a relay arm one-eighth inch in width and one-half inch in length is about the smallest practical size, and a relay arm three inches in width and two inches in length is about the largest useful size. These figures are given merely in the nature of suggestion, however, and should not be taken as limiting inasmuch as further development work may extend the range considerably.

Fig. 6 also illustrates an arrangement wherein the free end of the relay arm is slit at **265** to provide resilient contact fingers **267** carrying the movable contacts. In has been found that this type of relay arm is especially desirable when a large number of secondary circuits are carried on the relay arm.

It will additionally be apparent that normally-closed or double-throw relays may be designed in accordance with the principles of this invention. For example, Fig. 7 illustrates a possible arrangement for a double-throw relay. In this instance, the relay arm **305** has upper and lower movable plate areas **307**. Movable contacts **309** are mounted at the end of the arm, but the lead **319** therefor is embedded in the relay arm in insulated relationship from the plates **307**, as by using a laminated type of construction. A pair of fixed contacts **303** are spaced on opposite sides of the movable contact **309**, and resilient biasing fingers **304** project inwardly from the fixed contacts so that the relay arm is normally biased to a center position clear of the fixed plates **301** and fixed contacts **303**.

From the foregoing, it will be apparent that the invention provides a control that can be manufactured at small expense in comparison to present devices used for equivalent purposes. The insulating members or panels can be die cut and coated at high rates of production, and it is possible that conventional printing machinery may be used for this purpose. Assembly of the panels is obviously a very simple operation, and the assembled units may be readily stacked or mounted upon panels to form multiple-component apparatus. The block-like shape and the small size of the units also permits a very compact arrangement.

Additionally, it is to be observed that the relay arm is entirely enclosed in the device illustrated and described in connection with Figs. 1–3, and it will be apparent that the chamber containing the relay arm may be hermetically sealed to provide a controlled atmosphere. Such an arrangement may be desired when high relative humidity produces leakage in excess of that which can be adequately handled by the device. A sealed condition is readily achieved by compressing the insulating panels or by coating the outer surface of the device with lacquer.

Having thus described the invention, what is claimed and desired to be secured by Letters Patent is:

1. In an electrostatic relay having a pair of opposed electrostatically-actuated conductive plates, one of which is movable toward and away from the other plate; the improvement comprising a movable relay arm formed from a thin sheet of plastic insulating material, and a relatively thinner coating of conductive material adhered to one face over a wide area of said insulating sheet to form said movable plate, said relay arm being disposed so that the conductive coating thereon faces the other plate without an intervening solid dielectric.

2. In an electrostatic relay having a pair of opposed electrostatically-actuated conductive plates, one of which is movable toward and away from the other plate; the improvement comprising a first relatively rigid fixed panel of insulating material, a conductive coating adhered to said first panel to form a fixed conductive plate, a relay arm formed by an overlying relatively flexible movable panel of insulating material, and a flexible coating of conductive material adhered to said flexible panel to form the movable plate of the relay, said two coatings being disposed to face one another without an intervening solid dielectric.

3. An electrostatic relay as set forth in claim 2, wherein at least one of said coatings is formed by carbon resistance paint.

4. In an electrostatic relay having a pair of opposed conductive plates, one of which is movable toward and away from the other plate; the improvement comprising a relay arm formed from a thin resiliently flexible panel of plastic insulating material, said panel having a conductive surface forming the movable plate of the relay, said flexible panel being mounted with its conductive coating in opposed normally-spaced relationship to the other plate, said panel being at least in part movable against the resilient bias of the panel toward the other plate under an electrostatic force developed between the two plates.

5. In an electrostatic relay having a pair of opposed conductive plates, one of which is movable toward and away from the other plate; the improvement comprising a relay arm panel of flexible plastic insulating material, a coating of conductive material secured to one surface of said panel over less than the entire area thereof so as to form the movable plate, and a conductive contact element secured to said panel of insulating material in another area thereof so as to be in insulated relationship from the conductive plate-forming area thereon.

6. In an electrostatic relay having a pair of opposed conductive plates, one of which is movable toward and away from the other plate; the improvement comprising a generally rectanguler relay-arm panel of plastic sheet insulating material, said panel having conductive material secured to one face thereof to form the movable plate and

being mounted so that a free end thereof is movable, a row of contacts mounted in spaced relationship from one another along the free end margin of said panel, said contacts being in insulated relationship from one another and from the conductive plate-forming area of the relay-arm panel, and a second row of contacts fixed opposite said first row of contacts for cooperation therewith.

7. An electrostatic relay as set forth in claim 6, further including contact leads extending across said relay-arm panel of insulating material from the contacts at the free end thereof toward the other end thereof, said contact leads being disposed on the surface of said panel opposite from that bearing the conductive plate-forming area.

8. An electrostatic relay as set forth in claim 6, wherein said movable contact elements are formed as independently movable finger-like projections from the free end margin of the relay-arm panel.

9. An electrostatic relay as set forth in claim 7, wherein the relay arm panel further includes a second sheet of insulating material, said two sheets of insulating material being secured together with the contact leads therebetween, and conductive plate-forming areas formed on the two outer surfaces thereof.

10. An electrostatic relay comprising a pair of fixed rectangular panels, spacer means sandwiched between opposite margins of said panels to hold them in predetermined spaced generally-parallel relationship, a relay-arm panel mounted to extend into the space between said fixed panels, said relay-arm panel being in part movable toward and away from one of said fixed panels, said relay arm panel having a conductive plate-forming area on one face, the opposite fixed panel having a conductive plate-forming area on its inner face, a movable contact mounted on the movable part of the relay-arm panel, and a fixed contact mounted in the space between said fixed panels for cooperation with the movable contact.

11. An electrostatic relay as set forth in claim 10, wherein said relay arm panel is formed of flexible sheet material, at least one end of the relay-arm panel being secured in the spacer means along one margin of the relay.

12. An electrostatic relay as set forth in claim 10, wherein one end of the relay arm is clear of the spacer means so as to be movable between said fixed panels, and means interposed between the movable end only of the relay-arm panel and the fixed panel with the conductive surface, thereby to prevent the movable end of the relay-arm panel from engaging said fixed panel.

13. An electrostatic relay as set forth in claim 10, wherein said spacer means is a frame member formed with a rectangular center opening, thereby to enclose the plate-forming areas and contacts.

14. An electrostatic relay as set forth in claim 10, wherein said panels and spacer means are formed of insulating material, the respective conductive plate-forming areas being formed by conductive coatings adhered thereto, and printed-circuit leads extending from the plate-forming areas to the margins of the respective panels between the panels and spacer means sandwiched therebetween.

15. An electrostatic relay as set forth in claim 10, wherein said relay-arm panel is formed with a U-shaped cut which defines a flap, the margins of the relay-arm panel being secured by the spacer means and said flap being movable clear of said spacer means.

16. An electrostatic relay as set forth in claim 10, further including a frame-like fixed-contact panel formed with a rectangular center opening, the fixed contact being mounted adjacent the opening on one margin of said contact panel.

17. An electrostatic relay comprising a fixed conductive plate, a movable conductive plate mounted opposite the fixed plate and having a free end movable toward and away from the fixed plate, contact means mounted for actuation by the free end of the movable plate, a plate-energizing connection to the fixed plate at the end thereof adjacent the free end of the movable plate, a plate-energizing connection to the opposite end of the movable plate, and at least one of the plates being formed by resistive material.

18. An electrostatic relay comprising a plurality of stacked panels, a first one of said panels being formed with a conductive plate-forming area on its upper surface, a second superimposed panel having a movable section formed with a conductive plate-forming area on its bottom surface, and a third superimposed panel being formed as a spacer frame with a center opening for accommodating the movable section of said second panel, and a fourth superimposed panel adapted to limit upward movement of said movable section of the second panel.

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