

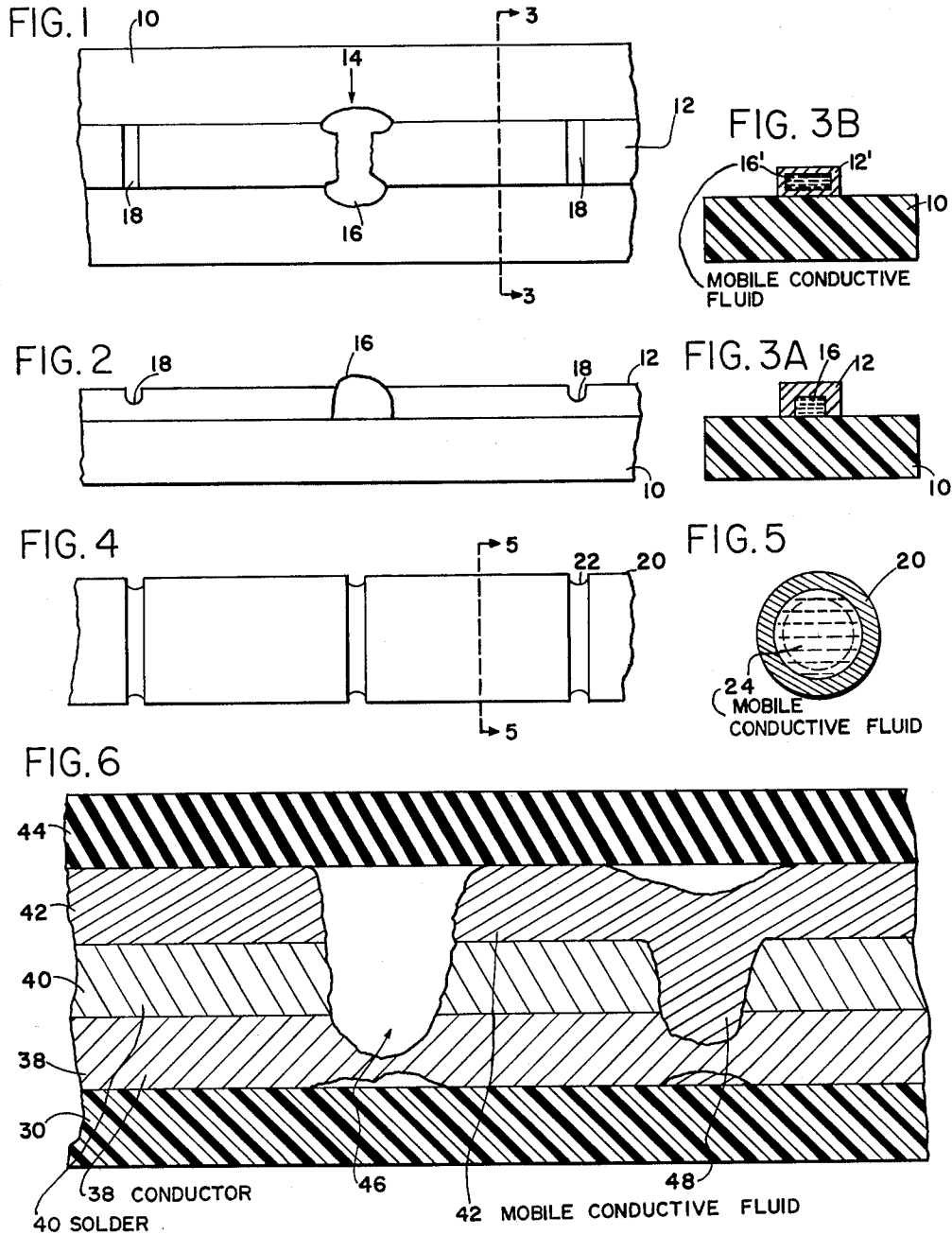
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SELF-REPAIR CIRCUIT APPARATUS

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SELF-REPAIR CIRCUIT APPARATUS
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This invention is directed generally toward self repair of circuits. More specifically the invention is directed toward a conductor which has associated therewith a mobile repair fluid. This fluid flows into breaks, both partial and complete, in the conductor to reestablish electrical contact between broken portions. One embodiment of the invention contains a fluid within and/or entrapped by a conductor. This fluid is of a type which hardens upon contact or exposure to the atmosphere. When a break occurs in the conductor, the fluid flows out from the interior of the conductor and while flowing will tend to harden and repair the break in the conductor. Another embodiment of the invention utilizes a material or coating which is placed on the conductor and which will flow into breaks upon application of heat. This heat may be either external or it may be heat generated from the high resistance path to current which occurs immediately prior to the breakage of a conductor.

It is an object of this invention to provide apparatus which has self-repair characteristics so as to prolong the useable life of a circuit.

Further objects and advantages of this invention will be apparent from a reading of the specification and appended claims along with the drawings wherein:

FIGURE 1 is a representation of a top view of a first embodiment of the invention utilizing a conductor on a printed circuit board wherein a repair fluid is contained within the conductor;

FIGURE 2 is a front view of the apparatus of FIGURE 1;

FIGURE 3A is a cross sectional view of FIGURE 1 through the lines 3—3;

FIGURE 3B is illustrative of an alternate form for conductor 12;

FIGURE 4 is illustrative of a second embodiment of practicing the invention wherein a repair fluid is trapped within a conductor;

FIGURE 5 is a cross sectional view of FIGURE 4 through the lines 5—5; and

FIGURE 6 is a cross sectional representation of a third embodiment of the invention wherein a mobile fluid is post-coated over the regular conductor so as to flow into breaks upon the application of heat.

In FIGURE 1, a printed circuit base means or substrate means 10 has attached to it a conductor means, conduit means or conductive element means 12. The conductive element 12 has a break in it in the area designated as 14. A material is shown between the left and right hand portions of conductor 12 and this material, which is a mobile conductive fluid or repair means or hardening resin means, is designated as 16. The conductor 12 may have indentations such as 18 which divide the conductor 12 into various portions or semicompartments. The conductor means or conduit means 12 is made such that there is a semicompartiment between the surface shown and the base means 10. To explain, and as is clearly depicted in FIGURE 3, the conductor 12 may have an inverted "U" or a rectangular cross section so that a compartment is defined by the coating base 10 and conductor 12. Fluid means 16 is thus within or partly entrapped by the conductor 12.

FIGURE 2 illustrates a side view of FIGURE 1 and shows the indentations 18 more clearly and the fact that the material 16 oozes out into the break zone 14 not only

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from the sides as shown in FIGURE 1 but also to some extent slightly above the surface of conductor 12.

FIGURE 1 contains cross section lines 3—3 and FIGURE 3A illustrates a cross section through this area. The same numbers are used for the same materials as are used in FIGURE 1. As will be noted, the conductor 12, as previously mentioned, has an interior portion which contains the mobile fluid 16. The indentations such as 18 are not shown in this view but it will be realized that these indentations partly close the space between conductor 12 and board 10 so that the fluid 16 cannot flow excessively from one compartment to another.

FIGURE 3B illustrates an alternate embodiment of a cross section for conductor 12 of FIGURE 1. As will be noted, this configuration utilizes a conductor 12' which totally encloses the entrapped fluid 16'. This may be contrasted with previously described FIGURE 3A wherein the fluid 16 is entrapped by the combination of conductor 12 and substrate 10. Again, as mentioned in conjunction with FIGURE 3A, the indentations such as 18 are not shown but will tend to partly close the space between the top and the bottom of conductor 12' such that the fluid 16' will not flow excessively from one compartment to another.

The mobile fluid 16 previously mentioned is also referred to as a conductive epoxy. These mobile fluids are available commercially from companies such as Hana Paint Company, Columbus, Ohio, and one epoxy from this source which is useable is (XC 6990A+XC 6990B).

Many other companies also produce similar conductive epoxy resins. (Even though they are called *conductive*, epoxy resins are inherently *nonconductive* and must be "filled" with conductive particles.) This mobile fluid 16 can either be a fluid plastic means with metal granula suspended within it or it can be an epoxy resin "filled" with conductive particles; or it can be some other fluid which is inherently conductive. The main idea is that it will flow from the interior of the conductor 12 into the break or broken area 14 to establish electrical continuity between the two portions of the conductor 12. It is not necessary that the fluid 16 harden but in most cases this will provide a more satisfactory bond than if the fluid stays mobile while outside of the confining portions of conductor 12.

Although the inventor has not produced any of the epoxy resin himself, it is believed that the purchased compounds contain the following ingredients in substantially the same proportions:

	Parts by volume
Silver granula	50
Epoxy resin	50

This mixture is then suspended in an adequate amount of a solvent such as methyl ethyl ketone. Upon the evaporation of the solvent, the resin will cure leaving the silver granula in sufficient contact to permit passage of electrical current.

To prevent evaporation of the solvent until a break occurs, it may be enclosed in a conductor or by a plastic or glass substrate as base means 10. It will be realized that this embodiment of the invention is the most useable in applications where the solvent can be retained in the resin until a break occurs and repair is necessary.

FIGURE 4 illustrates a method of confining the trapped fluid largely within compartments in a tube-like conductor 20. The tube 20 can be compressed or crimped by mechanical means and if the material, of which tube 20 is composed, is rigid enough it will stay in this closed or crimped position so as to keep the mobile fluid within it largely confined to the compartments shown.

The semicompartimentalizing of the fluid conductor is not essential, but is only shown as a means for prevent-

ing excessive flow of the fluid at a given break. Actually the viscosity of the fluid may be made adequate in itself to restrict excessive flow locally.

FIGURE 5 is a cross sectional view of FIGURE 4 through lines 5—5. In FIGURE 5 the conductor 20 is shown with mobile fluid 24 contained or partially entrapped therein. The mobile fluid may be any substance which will flow from the semicompartments and repair breaks such as discussed above in conjunction with FIGURES 1, 2 and 3.

In FIGURE 6 a cross sectional view of a printed circuit base or substrate means 30 is shown with a layer of copper or other conductor means 38 attached thereto. A solder layer 40 is shown attached on top of the conductor 38 and a post coating mobile fluid 42 is shown attached to the solder layer 40. Also shown is an insulative or covering layer 44 on top of the post coating mobile fluid 42. As will be realized, the figure is greatly exaggerated for clarity and is an out of proportion longitudinal view of a length of a printed circuit conductor. The mobile fluid may be any conductive substance which will flow either spontaneously or upon application of heat. One such substance is indium-gallium. According to experimental data, it appears that 90 parts by weight indium combined with 10 parts by weight gallium provides a useable alloy for the purpose. However, many other percentage combinations of this alloy are also useable in this and other applications. Another example of a material which is useable is indium-tin with 60 parts indium and 40 parts tin appearing to be one of the better percentage combinations. Other alloys with indium such as silver, lead, cadmium, bismuth, and mercury have also shown promise as a post coating material. FIGURE 6 shows two partially broken areas 46 and 48. The area 48 is an area which is already repaired and the post coating material 42 has flowed into the break 48 and provided good conductivity between the left and right hand portions of the main conductor 38. Break 46 as shown has just occurred. If heat is applied either through the use of an external heat source or due to the fact that current is still flowing through conductor 38 and accordingly encounters high resistance at the partial break, the mobile fluid or alloy 42 will flow into break area 46. In this manner more conductive material is provided to establish electrical continuity between the two portions of conductor 38 around the break 46. I define the word establish to include both reestablish and maintain since all embodiments will repair both partial and complete breaks in the conductor.

It has been found that a conductor made in this manner will not lose continuity as long as current is flowing through conductor 38 to provide heat for keeping fluid 42 mobile or flowing.

Substances such as indium-gallium 90-10 adhere to the solder 40 over a wide temperature range and do not flow away from the printed conductor. However, in case there may be a problem in keeping the mobile fluid 42 attached to the conductor 38 or the solder 40, a covering or insulative means 44 may be applied over the entire conductor unit. The coating 44 will confine the mobile fluid 42 to the area of the conductor and still, if the coating is not too thick, allow external heat to be applied so that the mobile fluid 42 will flow into broken areas. Of course, if the heat is obtained from the conductor 38 upon partial breakage, then it will not matter particularly how thick the coating 44 is. Further, if the covering 44 is only to be used to confine the material 42, it does not have to be insulative, but can be conductive. It is realized that breaks probably will appear in the conductive covering 44 if they appear in conductor 38 but substantial confinement of the mobile fluid 42 will still result in spite of this possible detriment.

While the conductor of FIGURE 6 has been shown and described with the solder 40 and the covering material

44, it is to be realized that these are not required for the practice of the invention. It is to be further realized that this invention is not restricted to the use of printed circuit boards but that it can be used with free hanging wires in some applications. One example of such an application would be where many insulated wires are tied together and the breakage of one wire will not substantially affect the position of the two ends of this wire so that the post coating or mobile fluid such as 42 can flow and establish good electrical contact between the end portions of the broken conductor. Also, in many instances, the insulation itself will prevent separation while self repair is occurring.

Other examples of the use of a permanently fluid conductor or a low temperature melting alloy coated over otherwise standard conductors are (1) welded junctions, and (2) component leads (within the component). Many electronic failures are due to mismatches in thermal coefficients of expansions of component leads and potting compounds. A flexible, remeltable material such as indium-gallium applied to leads within a component allows for a wider range of expansions and contractions of the various parts constituting a system.

While certain illustrations have been given of possible applications of the invention, it is to be realized that the invention is not restricted to the illustrations shown. In other words, the invention lies in the use of a mobile conductive fluid which is used to reestablish contact between completely broken or partially broken main conductors such that the conductor can still be used in a circuit to provide electrical continuity within this circuit. Therefore I wish to be limited not by the drawings or specification but only by the appended claims.

I claim:

1. Apparatus of the class described comprising, in combination:

printed circuit base means;

conductive conduit means attached to said printed circuit base means; and

conductive resin fluid means contained within said conductive conduit means, said conductive resin fluid means containing solvent means which evaporates upon exposure to the atmosphere, said conductive fluid resin means escaping from said conductive conduit means through separations of said conductive conduit means, and said conductive fluid resin means being adapted for hardening in said separations of said conductive conduit means to thereby establish electrical continuity throughout the length of said conductive conduit means.

2. Apparatus of the class described comprising, in combination:

conductive conduit means; and

conductive resin fluid means confined by said conductive conduit means, said conductive resin fluid means containing solvent means which evaporate upon exposure to the atmosphere, said conductive fluid means escaping the confines of said conductive conduit means through separations of said conductive conduit means, and said conductive fluid means hardening in said separations of said conductive conduit means to thereby establish electrical continuity through said conductive conduit means.

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