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FAILURE MECHANISMS OF ELECTROMECHANICAL RELAYS ON PCBAs: PART I

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INTRODUCTION

Many printed circuit board assemblies (PCBAs) have relays that are soldered to the PCB. If such an electromechanical component fails, it can cause the whole device to fail, just like any other electronic component. The spectrum of root causes that lead to an increased contact resistance or a complete contact failure is totally different from what usually occurs in the electronics domain. This article provides a detailed analysis of these failures and the corresponding root causes, many of them self-centering.

In this overview about failure mechanisms of electromechanical relays, the failure analysis discussed and the corresponding root causes are limited to contact failures between two contacts in relays that are used to switch small loads (Fig. 1). The relay has five terminals. The two terminals on the left in Fig. 1 are wired to a coil that creates a magnetic field when a current is applied. The magnetic field moves the middle contact of the three terminals on the right in Fig. 1, which connects or disconnects to the left and right contact. Nickel/silver or silver/tin oxide is used as the contact material. Sometimes they are gold plated, but the failure mechanisms are incidental in the cases shown.

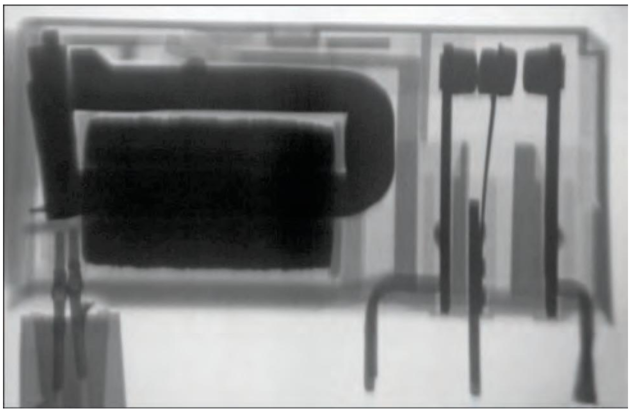

Fig. 1 **X-ray of a common electromechanical relay. If an electric current is passed through the coil, it generates a magnetic field that activates the hinged armature on the left. The movement is transferred to a plastic slider, and the movable contact—here in the middle of the three contacts—either opens (normally closed) or closes (normally open) a connection with the fixed contacts left and right. The pins are soldered to the PCB.**

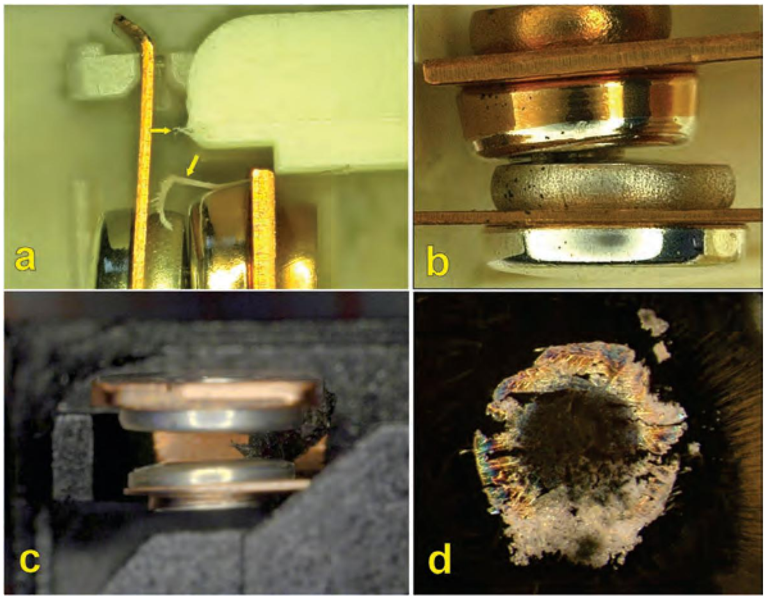

Fig. 2 **(a) Plastic chip from an edge of the plastic part. (b) Flux particle from a remote solder joint. (c) Solid plastic chip from a plastic part. (d) Flattened plastic particle exactly in the middle of the contact point**

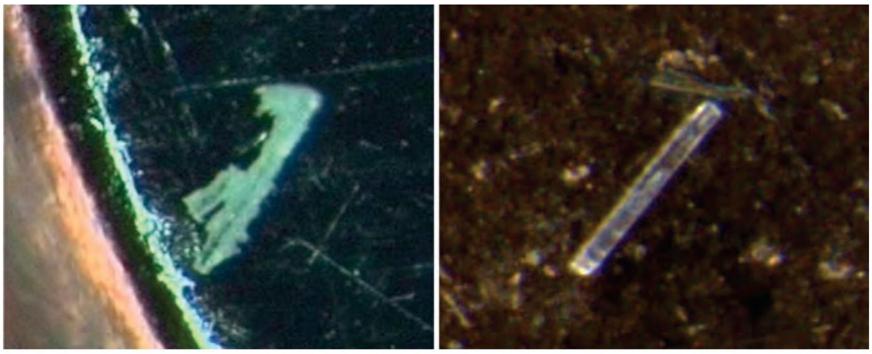

Fig. 3 **Glass fibers (with and without plastic residues) on the relay contacts**

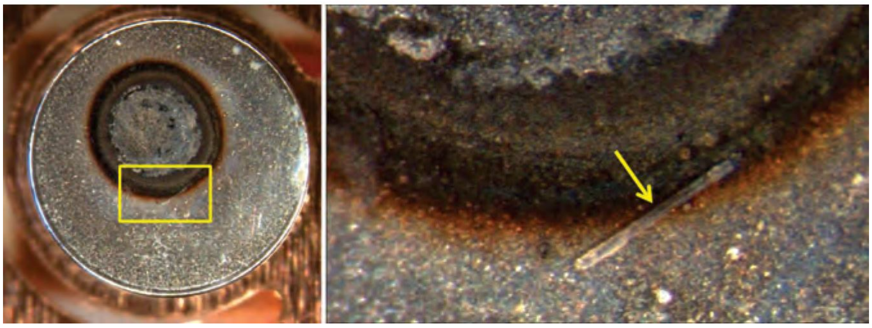

Fig. 4 **A glass fiber caused arcing between two relay contacts. The fiber is outside the region of the shortest distance between the contacts, so it does not sink into the molten silver surface. The current is alternating, so the arc is not stationary but moves around. The contact resistance is high because there is no physical contact between the silver contacts.**

CONTACT FAILURE CAUSED BY NONCONDUCTIVE PARTICLES AND FILMS BETWEEN THE CONTACTS

The most common failure type for an electromechanical relay is a nonconductive particle lodged between two switching contacts. Frequently, the particle is a chip from a plastic part. Particles are also formed if metal parts scrape against plastic surfaces. This results in oxidized metal wear as well as plastic wear (Fig. 2a,c,d) and glass fiber fragments from the glass-fiber-reinforced plastic (Fig. 3, 4). Further, solid flux residues from soldering the copper wires of the coil to the pins can be found on the contacts (Fig. 2b).

It has been observed that nonconductive particles between two contacts do not appear by chance, but this is a self-centering failure mechanism.

The mechanical shock caused when two relay contacts open causes particles in the relay to bounce. An inhomogeneous electrical field is simultaneously built up, which exerts a force on the particles. They are pulled in the direction of the force. It may take tens of thousands of switching operations, but, at some point, the particle finally reaches the center of the force. A very thin film of oil is often used in relays to prevent this type of failure. These particles adhere to this thin film of oil and do not move, due to inhomogeneous electrical fields.

CONTACT FAILURE CAUSED BY CONTACT OIL

If contact oil is used in electromechanical relays, the type of oil used and the quantity applied are very important factors. Perfluoroether is common and a good choice; however, the quantity is critical. If the oil is applied undiluted in a layer more than a few micrometers thick, then another self-centered failure mechanism can occur. Particles stick on the oily surface (Fig. 5a). If the oil film is too thick, it acts as a liquid, and the fluid coalesces in the capillary around the contact point (Fig. 5b). When the contacts separate, the surface of the oil is pulled into the direction of the contact point, as are the particles that have attached themselves to the fluid (Fig. 5c). After a number of switching operations, the particle reaches the contact point (Fig. 5d) and causes the failure. Figures 6 and 7 show examples of a glass fiber and a plastic particle that have been pulled to the contact point.

ELECTRICAL ARCING DUE TO LARGE PARTICLES BETWEEN THE CONTACTS

If a large particle prevents the contacts from being tightly closed, an electrical arc may build up, depending on the diameter of the particle and the applied voltage. In air, there is a basic rule that an electric field of 1000 Volts/mm distance (1 V/μm) is required for an electric arc. This means that 24 V can arc over a distance of 24 μm. Oil between the contacts usually overrides this rule. An arc is nearly impossible. However, if an arc does form, the oil will evaporate, catapulting the contact open. A sizzling sound can be heard, because this effect may be repeated several times.

If the particle is located somewhat away from the shortest distance between the contacts, it will not burn or sink into the molten contact surface. The arc can continue to burn for a long time. If direct current is involved, then material can also be transported, forming a tip and a hole. The failure manifests itself in such a way that a higher contact resistance is measured (Fig. 8, 9).

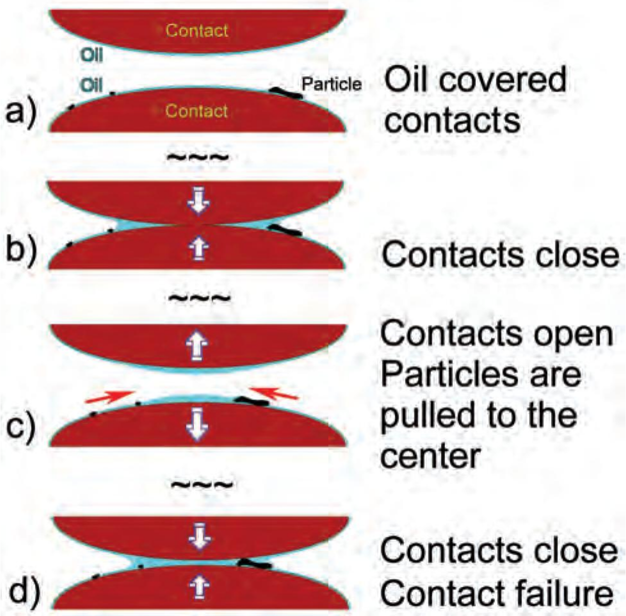

Fig. 5 **(a) Particles stick in the oil on the contact surface. (b) Surplus oil flows into the capillary between the contacts. (c) Opening the contacts pulls the surface of the oil and the particles to the center of the contact. (d) Particles can cause contact failures.**

SILICONE OIL OR SILICONE VAPOR IN AN ELECTRIC ARC IS TRANSFORMED INTO SILICON DIOXIDE

Contact failure is not caused just by solid particles. If electric arcs occur and silicone oil or silicone vapor is present, the silicone is oxidized to silicon dioxide (SiO_2), in the solid form commonly known as quartz or glass. This nonconductive silicon dioxide condenses as an insulating layer in just the contact region. The process is again self-centering because the highest fields occur at the shortest distance, which is the contact region (Fig. 10).

Part II of this article, which will appear in the May issue of *EDFA*, will discuss the formation of nitrous gases caused by arcing and the formation of phosphoric acid crystals on contacts, resulting from the addition of red phosphorus as a flame retardant to certain plastic materials. It also will discuss why sealed relays, which pop open during soldering, are prone to precisely this type of failure. Finally, a failure mechanism due to wax, which is used as a lubricant for the enameled copper wire of the relay coils, will be discussed.

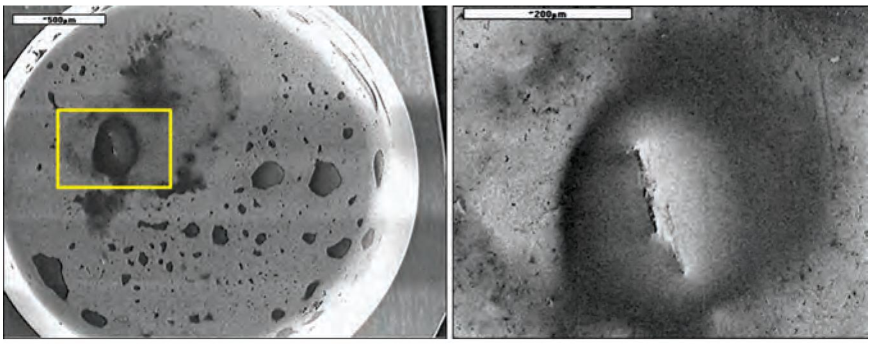

Fig. 6 **Contact failure caused by a glass fiber pulled to the contact point**

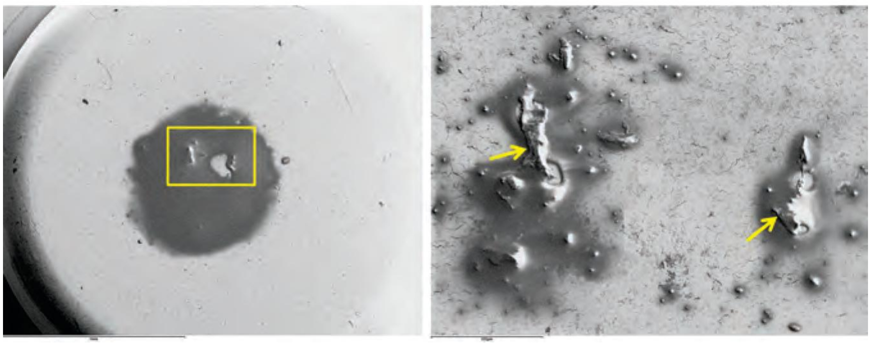

Fig. 7 **Contact failure caused by plastic particles pulled to the contact point**

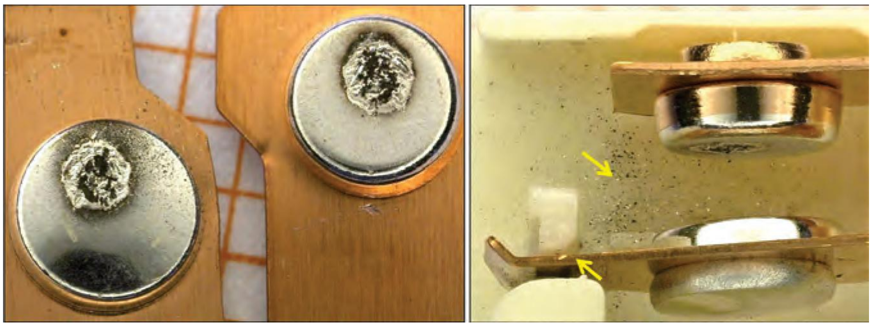

Fig. 8 Contact failure caused by metal wear. Arcing occurs and burns the contact surfaces.

Fig. 9 If a particle blocks the contact, and if the distance between the contact surfaces is not too large, arcing can occur (basic rule: 1 V/µm in air). The arc burns at the point, which represents the closest distance between the contacts. If the particle (see arrows for the mark) is located somewhat away, it will not burn or sink into the molten contact surface. Material can be transported if direct current is involved, forming a tip and a hole.

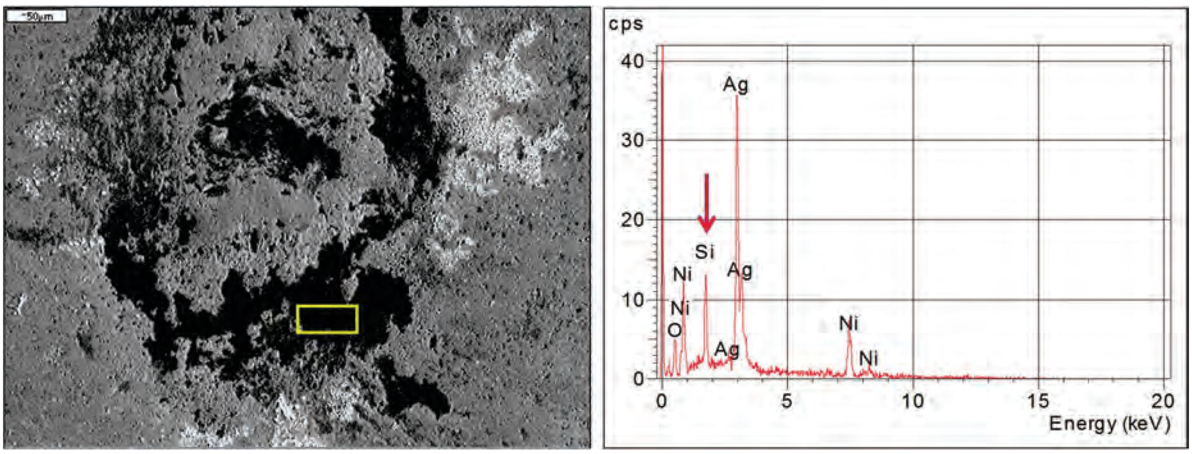

Fig. 10 The black regions in the scanning electron microscopy image of the contact point of a failed relay contact indicate nonconductive layers. They consist of silicon dioxide, shown in the energy-dispersive x-ray spectrograph. The SiO_2 is produced in the electrical arc from silicone vapor and condenses in the contact region.

ABOUT THE AUTHOR

Gert Vogel studied physics in Stuttgart. He has been with Siemens for more than 32 years. Dr. Vogel was a semiconductor technologist in Siemens' DRAM production in Munich and Regensburg for seven years. He then moved to Siemens Amberg, where one of his specialties is the failure analysis of electronic components on printed circuit board assemblies. He led a tutorial, "Avoiding Flex Cracks in Ceramic Capacitors," at ESREF 2015. This was followed by a tutorial, "Creeping Corrosion of Copper on Printed Circuit Board Assemblies," at ESREF 2016.