

Detection of Component Fires in Electronics*

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ABSTRACT

Some observations are reported on fire hazards in small electronic components. Certain types of resistors, capacitors and transformers have been examined. A method for fast detection of such occurrences is described. The method is economic and relatively easy to use. It makes use of the melting of solder wire in an insulating tube which is installed close to the components to be monitored.

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Several fires in electronic components occurring during recent operations of an experimental facility at the Stanford Linear Accelerator Center have prompted this report. In all cases someone was on hand who was able quickly to isolate the source. When the equipment was powered down most fires extinguished themselves, but cases of burning insulation required further action. A substantial quantity of equipment is, however, remote from personnel stations, and also, for stability reasons, it is considered desirable to keep certain equipment switched on even when there is no other reason to have people on hand. Consequently there would be some value in an automatic means for the early detection of component fires.

Components which have caused heat damage were carbon composition resistors, ceramic capacitors, power transistors and power transformers. It is characteristic that the only early sign is a more or less strong smell. Usually there is a negligible release of smoke until, presumably, the fire has spread broadly.

While looking into the problem we have found that the commonly used carbon composition resistors actually become nearly short-circuited for a substantial time during a typical burn out cycle (Fig. 1). The exact behaviour depends on the voltage and current available, of course, but even a 1/4 watt resistor is capable of sinking ~ 10 watts for five minutes or so before disintegrating. Resistors have been seen to glow brightly and continuously. To simulate in-circuit failures, tests carried out in this study have usually limited the current in the test components to less than 1.5A, with applied voltages up to 25 or 30V.

It was felt that metal film resistors should show better characteristics than the carbon composition type. However, it was found that this kind also burns when overpowered. A gradual increase in voltage from a safe value can cause charring, and a steady increase in resistance until the component goes open circuit. On the other hand, if a sudden accident applied, say, 25V, a resistor of ~ 50 ohms would soon become a short circuit. For half a minute or so, depending on the power available, it could glow white hot before becoming open circuit.

Investigation of transformer failures showed that a filament transformer (6.3V, 3A) with accidentally shorted secondary leads, heated itself to more than 400°F at places on the external wrappings within 7 or 8 minutes, while continuing to function. The ultimate temperature was not measured.

Surprisingly, fires starting in ceramic capacitors are known. These must normally be caused by physically damaged components or manufacturing faults, and are difficult to simulate. An attempt has been made to do so by causing electrical breakdown in capacitors of 50V working range, 1 microfarad to 0.01 microfarad (typically requiring 5 to 10 times the specified working voltage). Over-current protected power supplies with low current capacity were used for this step. Some of the capacitors were then found to have low resistance (say ~ 4 ohms) at $\sim 1.5\text{V}$. Tested with a high current source, such capacitors were capable of drawing 20A at 4V for 20 seconds or so before power was intentionally switched off. The components were white hot and released flame and some smoke.

The damage was initiated in one area of the capacitor, presumably where the breakdown first occurred. The amount of heat released by a capacitor is strongly dependent on its physical size. Capacitors of 0.01 microfarad have not been seen to release more than a few watts for 1-2 minutes.

Not all component fires would broaden to a conflagration. Nonetheless many of them are not self limiting and could cause substantial damage, sometimes as a chain reaction elsewhere in the circuit. In high voltage equipment, near line power, near cable insulation, and in some electromechanical equipment, the risk is more severe.

In seeking a method of protection, some unusual characteristics of electronics equipment must be borne in mind: high component density; very low thermal mass of many components and consequently low power levels needed to cause damage; electrical environment; poor accessibility; need for retrofitting the protection to existing equipment.

Present techniques may be able to meet one or more of these points, and may be applicable to special cases.

- : Temperature sensitive switches. These do not presently seem applicable to a large number of densely packed miniature components.
- : In-line miniature fuses. In many cases these will provide protection from short circuits, but may not be retrofittable. They may not be useable in cases of multiple supply voltage levels and may not respond in cases of multiple parallel channels of electronics.

- : Temperature sensitive resistance wire or components. The former has difficulty distinguishing between a generally high operating temperature and a local acute problem. Thermistors, etc., used at the component level are expensive since they would require multiple channels of monitoring.
- : Smoke detectors. These have been shown not to work in the circumstances under discussion. A brief attempt has been made to find a smoke-prolific coating for components which would make fires more detectable, but without success.
- : Temperature sensitive insulation. There is a commercially available fire detecting system based on a tightly twisted wire pair separated by insulation ¹⁾. The insulation melts at a predetermined temperature causing the wires to short together. The materials and construction appear to make the product applicable only to large scale equipment (cable trays, etc.) since it is of large size, stiff, and of high thermal capacity.

A search has been made for a suitable temperature sensitive medium of low thermal capacity but capable of covering substantial areas, stable, easily handled, and of low cost. It was intended to be placed as close to the potential hazard points as possible to give early warning. It should not encumber the equipment excessively, nor itself add to the hazard. It was decided to indicate only destructive temperatures rather than risk false alarms for marginally overheated but functioning components.

The melting phase change of Sn-Pb 63:37 solder is sharp, and at a low enough temperature (362°F) to respond satisfactorily to most electronic component burning. Other solders can conveniently provide a range of different melting or softening points (as low as $\sim 250^{\circ}\text{F}$) for specific applications.

The solder must be isolated from the components to be protected by an insulating sleeve. This must have walls thin enough to permit adequate heat transfer, yet be able to withstand the external temperature long enough for the solder to melt. For our purposes PTFE ("Teflon", M.P. 621°F) appears to be adequate. Its adhesive qualities are poor, but it is mechanically excellent otherwise, and its electrical resistance and breakdown properties allow its use with sensitive circuits and around comparatively high voltages. It does not support combustion.

The simplest fire sensing device relies on the surface tension of molten solder and its inability to wet PTFE. When a solder wire melts at a point along its length it quickly draws back along the unmelted wire, forming a ball on either side of the melted region and leaving a gap in the middle.

A constraint on the design is that there should be sufficient room for the solder to deform like this. On the other hand the air gap between PTFE and solder must not form a significant barrier to heat transfer. It has been found that, for general purposes, solder wire of 0.020 in. diameter in tubing of 0.028 in I.D. and 0.010 in (nominal) walls performs

adequately while remaining easy to handle. However, for access to tightly packed components, sleeving of 0.030 in O.D., 0.012 in I.D. containing solder of 0.009 in diameter has been assembled without undue difficulty, and tested successfully. Its lower wall thickness and small thermal capacity shorten its reaction time to external heat. It is more likely to ablate away than the thicker material, but in instances where a heat source was allowed to sever the PTFE, the solder retreated from the cut region and was not released. Alternatively, when a heavier teflon-solder combination was flattened in a press to allow fitting in narrow spaces, the melting and separation properties were retained. The presence of resin flux in the solder does not appear to be important.

The separation of the solder filament seems to be assisted somewhat by gravity. A fixed temperature source which caused separation in an average of 16 sec. with horizontal solder took only 10 sec. when the solder was tipped at any angle over 10° . The solder even separates when heated at the lowest point of an arc in a vertical plane. It is necessary only that the hot component be within ~ 0.01 in of the sleeving, thus getting sufficient fast heat transfer.

Thus the simplest case is a PTFE sleeved wire of a low melting point alloy. In use, this is routed throughout the circuit to be protected, in such a way as to touch the components at risk. It is most convenient to make a transition to, for example, wire-wrap wire at either end for rugged and easy electrical connection. This can be done using a light touch with a small soldering iron. In the interests of ruggedness it is best to stop the solder short of the end of the sleeve, thus protecting

it from severe kinking at the end (Fig. 2). The sleeving can be held in place in the circuit by various convenient techniques, including fast setting wire tacking compounds. Gluing to the specific components to be monitored would require a glue that can withstand temperature above $\sim 450^{\circ}\text{F}$, a property not readily found in organic glues.

Flexible "fuses" of this type have been tested successfully on overheating components of all four types discussed above. They respond before neighboring components are affected by the heat. For sources below about 5W, however, they normally do not respond.

A wide range of electrical sensing techniques can be applied. One end of the sensing wire can be grounded, or alternatively the device can be completely isolated electrically from the circuit to be protected, since it is only necessary to monitor the continuity of the solder. This might be done by TTL circuitry mounted on the board being monitored, possibly even controlling the local voltage regulation. Other approaches could be to connect to external relays or to connect the solder in series with the power line, etc.

An example is used at this laboratory for modules of 32-channel per card sample-and-hold circuits (SHAM IV) mounted in a modified CAMAC crate. The read and write lines of the dataway, not used by the SHAM's, were connected to test the presence of a SHAM module and whether its heat sensing element is intact. The unit monitoring these lines is powered independently of the SHAM crate and can interrupt power to the crate on detecting a heating incident, while continuing to indicate which unit showed the fault by a front panel LED.

The amount of heat sensing material added to the equipment is quite small. The fluid solder would be contained in the inert outer sleeve unless the fire were to build up, and even then the sensor would contribute negligibly to the possible flammable load and damage.

There may be applications where the surface tension and gravity effects are not considered positive enough. An example is the selection of a low temperature softening alloy with a higher melting point. Separation can be effected by loading the solder with a spring. This has successfully been demonstrated, and requires only a few grams tension but an adequate spring extension, typically 1/8 to 1/4 in.. Electrical contact must be arranged so that the contact wire is not rigid enough to negate the light opening tension of the spring. The disadvantages are obvious - extra room for the spring movement and the electrical connection, and more cost in assembly of the unit. However, examples of this type constructed and tested were not particularly difficult or expensive in components or time, and would add negligibly to the cost of circuits which they could protect.

FOOTNOTE

1. "Protectowire": The Protectowire Company, Hanover, MA.

FIGURE CAPTIONS

1. Schematic representation of resistance as a function of time for a resistor loaded with too much power.
2. Cross section of part of a heat sensing assembly.
 - a) Solder
 - b) PTFE sleeve
 - c) Wire wrap connecting wire with insulation.

Biography:

R. Clive Field was born on February 11 1943 in Belfast, N. Ireland. He obtained a B. Sc degree at Queen's University, Belfast, and a D. Phil. at Oxford University, specializing in Elementary Particle Physics. Since 1968 he has worked in California, first at Lawrence Berkeley Lab, and then at Stanford Linear Accelerator Center, carrying out further research on elementary particles.

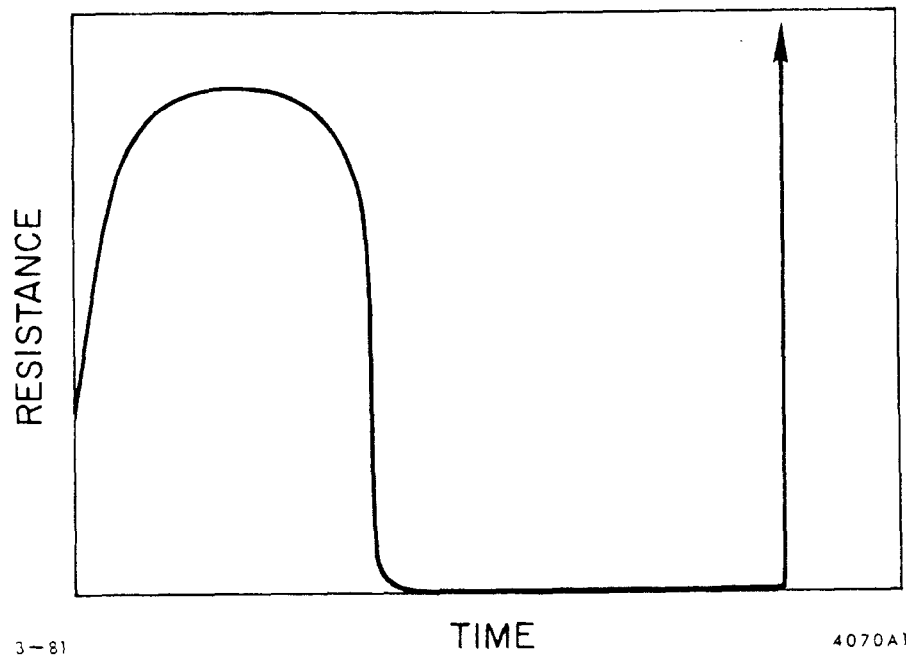


Fig. 1

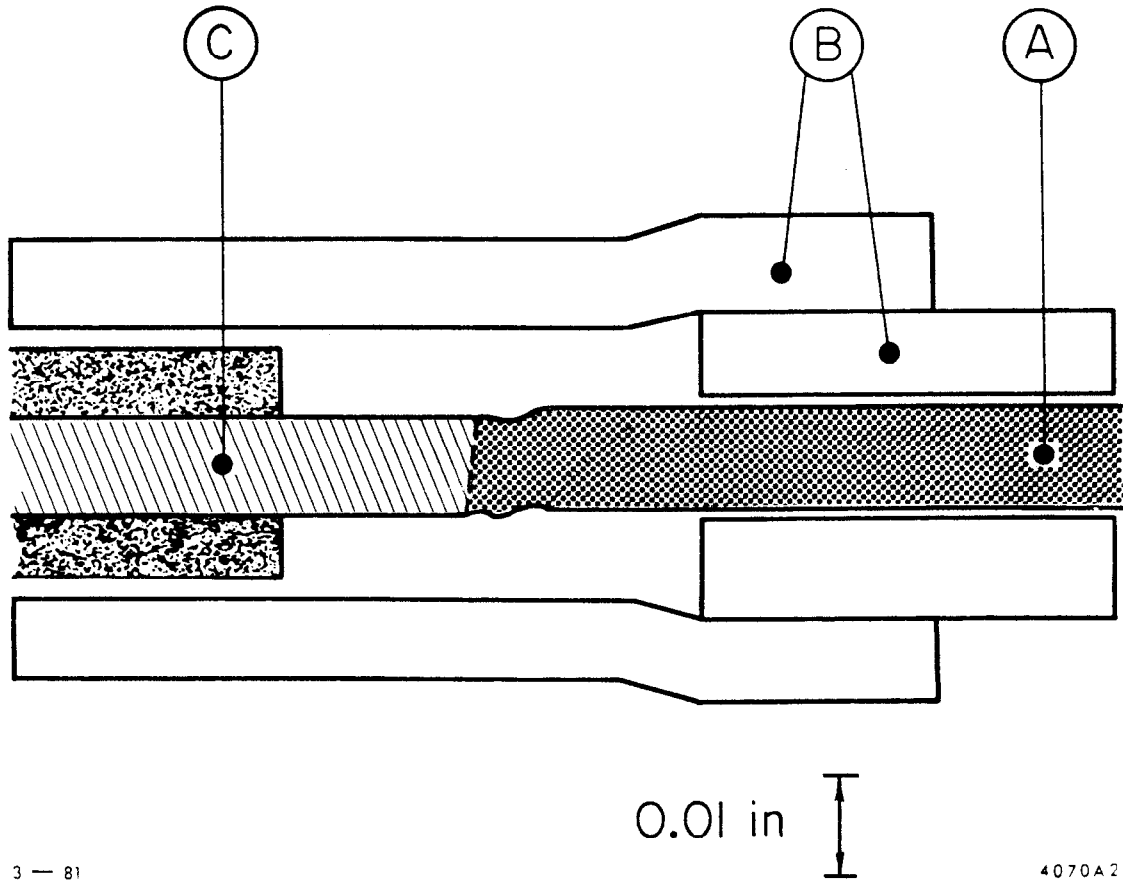


Fig. 2