

capacitors in series you can get good reliable operation with a voltage that would break down any presently made single section capacitor. On the other hand, electrolytic capacitors tend to be self-balancing when put in series but there is a limitation to how far you can go. In other words you can't build them up for 10,000-volt operation.

**Mr. Wright:** Can the change in capacitance following protracted operation at subnormal voltage be predicted? Can you give a rule of thumb formula?

**Mr. VanBuskirk:** It can't too well be predicted because from all the tests we've made it doesn't follow a set pattern. Again as stated on another question, the worst condition is no voltage. There, if you take a condenser on shelf life—we had one once that was nine years old—the capacity on that unit also was a very few per cent different from the initial value after nine years with no voltage. The capacitance change with protracted operation at sub-normal voltage or with no voltage is not a high enough percentage that you would want to say it's eventually going to an infinite point. Fred Keller of the Aluminum Company of America says there is a definite increase of capacity with operation at sub-normal voltage. I'm giving my personal opinion in the matter. If the capacitor is truly operated; that is, if there is any voltage on it at all within reasonable limits you are not going to be able to detect too big a change in the capacity after this operation at subnormal voltage compared to what it would be operated on full voltage.

**E. Seif** (Burroughs Adding Machine Corp.): How do you define failure of an electrolytic capacitor?

**Mr. VanBuskirk:** That's when the capacitor fails to perform the function it was put into the circuit to perform. It can do this by various means, for example, it can short-circuit, it can become low capacity, high resistance, or high leakage.

**Mr. Seif:** Do you consider as a failure the temporary damage to the electrolytic which is self-healed?

**Mr. VanBuskirk:** At this point, he is referring to the sparking in the electrolyte. It could raise a lot of trouble in computer operations, but the voltages we tried to recommend here will not give sparking in the electrolyte unless there is some additional failure in the unit, that is, a hot spot developing that lowers the sparking potential of the electrolyte. Any temporary damage which is self-healed you want to eliminate because it does give a temporary surge current, and the type of failures that are self-healed of course are a sparking where the oxide film breaks down or deteriorates and then is reformed by the surge current. Then, of course, in low temperature operation electrolytic capacitors may be cooled down to the point where there is no measurable capacity left. This is a temporary condition and the capacity is as good as new when it is brought back to normal temperature.

**C. W. Watt** (Massachusetts Institute of Technology): Are MIL-specification electrolytic capacitors good enough for computers?

Are non-MIL-specification tubular electrolytics good enough for computers?

**Mr. VanBuskirk:** With the proper choice of the rating for a particular application it is possible to get excellent reliability from either of these types of capacitors in computers. The same care in the choice of the rating must be made for these capacitors as for any other. Naturally, if the application should not be serviced by electrolytic capacitors, then neither of these types will operate satisfactorily.

There is one drawback to the use of MIL-specification electrolytic capacitors in computers. These capacitors are made the same way that capacitors were made when qualification approval was obtained on the capacitors. There is a reluctance on the part of manufacturers to be changing any of the designs of MIL-specification electrolytic capacitors, as approval from the Armed Services must be obtained prior to inclusion of a change in design. As a result, MIL-specification electrolytics are frozen in design and improvements developed subsequent to such freezing are not included in the MIL-specification capacitors. For this reason a better capacitor usually can be made than the MIL-specification type, as the electrolytic capacitor industry continues to progress.

Generally, MIL-specification electrolytic capacitors should be more reliable than the standard highly competitive designs. Then, in turn, up-to-the-minute designs for computer use with maximum reliability will be somewhat better than the MIL-specification type.

## Resistor Reliability—Whose Responsibility? Some Case Histories

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### INTRODUCTION

COMPONENT RELIABILITY is a subject that has had the attention, in whole or in part, of almost every electronics symposium or conference the last few years. The failure rate of equipment, claimed to be caused by component failure, warranted this attention. As a result the cry has been for better and better components. This is good. Components should be and are being constantly improved, just as computers and other electronic gear should be constantly improved.

However, this cry for better and better components has been based on the assumption that the component is the villain of the piece. If the component fails or is unreliable, it is the fault of the component. In discussions on this subject one hears that the component cannot stand high temperature or low temperature, it cannot handle overloads, it is unstable, it changes too much for one reason or another, it opens circuits, it breaks down. And so on and on. And the usual clichés are trotted out, as typified by—"A chain is no stronger than its weakest link," and "The dependability of each component determines the utility of the assembly." In brief, the burden of reliability of electronic gear is thrown on the component.

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Now, there is no denying that components, like human beings and even computers, are imperfect. They have their weaknesses and inadequacies. And let it be said at the outset that the component manufacturers recognize the need for improvement and are doing everything possible to eliminate these inadequacies. However, there is another side to this coin of component reliability, and it is the object of this discussion to show this other side. Real life, thumbnail sketches are cited, illustrating examples of component failure and unreliability which have nothing to do with the component but everything to do with its abuse and misuse. The symptom of unreliability is in the component, but the real cause is elsewhere. From this analysis some suggestions follow, which it is hoped will prove constructive in obtaining more reliability from existing components.

#### CASE 1

A  $\frac{1}{2}$ -watt wire-wound resistor molded in bakelite, resistance 120 ohms, used in a sound system circuit, failed occasionally by explosion, like a firecracker. Normal power dissipated in the resistor was appreciably below the rating. The trouble was ascribed to defective resistors. Careful investigation disclosed that momentary line faults resulted in line voltage of 110 volts appearing across the resistor, producing 100 watts in the resistor, 200 times its rating. With the necessary protective measures, no failures have occurred. Now, it may be said that resistors should be capable of handling overloads. This is true, but hardly 200 times. This is a case where the designer should have anticipated possible faults which would affect reliability and guard against these faults in advance.

#### CASE 2

High-stability deposited carbon resistors were used in an amplifier. The prototype equipment produced by the development company was satisfactory. The ultimate manufacturer found his amplifiers did not meet specifications and eventually traced the trouble to the deposited carbon resistors which were claimed to be unstable. They were considerably outside the original 1 per cent tolerance.

Investigation disclosed that the manufacturer sprayed the resistors with a fungicidal compound which attacked the insulating coating of the resistor and eventually the resistance film, causing high resistance changes. The prototypes were not treated this way. Too often the user assumes the component should be capable of withstanding any treatment he applies to it. Not infrequently the user processes components without consideration or knowledge of the effect of such processing on the component, and without consulting the component manufacturer. Many such failures can readily be prevented by prior consultation with the component manufacturer who can frequently guide the user to the correct materials to use, if necessary.

#### CASE 3

Miniature  $\frac{1}{4}$ -watt composition resistors with a very thin bakelite molding were found to be mechanically unreliable, which would eventually lead to electrical instability. These resistors, oddly enough, were assembled in the equipment in such a manner that to solder dip the leads it was necessary to immerse the entire resistor, body and leads, in a molten solder bath at 520 degrees F. Although the resistance value did not change too seriously (this change was not the main trouble) the bakelite body showed signs of cracking. Needless to say, resistors of this class are not designed or intended to meet this kind of service.

Here again there seems to be an underlying assumption that resistors or components in general should be able to withstand any kind of treatment to which the user wishes to subject them.

#### CASE 4

Deposited carbon resistors—150 of them—assembled in a computer were claimed to be unreliable in that about 70 per cent of them departed anywhere from 1 per cent to 10 per cent from the original 1 per cent tolerance. The 150 resistors were to be removed and replaced by another make. Here was a situation in which the end equipment had not yet failed but failure was anticipated because of the above assigned reason. Twelve tagged resistors were produced showing deviations of 1 per cent to 10 per cent. A check measurement on a Wheatstone Bridge showed all to be within 1 per cent. The 150 resistors in the computer were measured and only one was outside the 1 per cent tolerance—and the deviation was nominal. Here is a case of guilt by assumption and assumed unreliability, not based on fact or actual performance, but based on inaccurate measurements. The reason for the inaccurate measurement was never determined or revealed.

#### CASE 5

A 2-watt composition resistor, used far below its rating, was giving serious field trouble in that its value changed excessively and the bakelite insulation showed signs of discoloration, pointing to excessively high temperature. This resistor had proved satisfactory in engineering development models, and in the initial engineering prototype samples. Yet all production equipment showed this field trouble. After the usual trouble shooting, a comparison of prototype and production models disclosed an apparently minor difference. In the prototype, the 2-watt resistor was assembled at some distance from a 10-watt wire-wound resistor operating at quite a high temperature. For reasons of wiring simplification, the factory assembled the two resistors cheek to cheek in production. The result of the direct heat transfer from the power resistor to the composition resistor, the temperature rise in the composition resistor itself, and the ambient temperature,

was an operating temperature far in excess of that for which the composition resistor was designed. The correction was obvious. There was nothing wrong with the resistor, there was everything wrong with its mounting. No consideration was given by the manufacturer to the effect change in assembly might have on the resistor.

#### CASE 6

A 1-watt deposited carbon resistor specified at 1 per cent tolerance departed sufficiently from its tolerance limits in the circuit application to impair performance. In operation the resistor changed about 3 per cent to 4 per cent which was claimed to be objectionable. Operating at full load this change is not bad for a deposited carbon resistor, regardless of its initial tolerance. This class of resistor has a relatively high temperature coefficient—about 200 to 600 parts per million depending on resistance value. At full load the temperature rise is about 80 degrees C. Depending upon resistance value this resistor could change as much as 4 per cent because of temperature rise alone. And if the ambient temperature were appreciably higher than 25 degrees C. the change would be greater.

The difficulty here is that many engineers confuse or equate close tolerance with stability. One has nothing to do with the other. It is possible for a 20 per cent resistor to be far more stable than a 1 per cent resistor. In this particular instance, if temperature stability was as important as claimed, a resistor of lower-temperature coefficient was clearly indicated, or a larger deposited carbon resistor of the same type used below its rating should have been used. Unfortunately, analysis of all factors involved in the use of components is frequently not made, and the path of least resistance is to blame the component for the failure of the user engineer.

#### CASE 7

Trouble was experienced with a special type of resistor presumed to be a high-stability type. This time the trouble was real; there were wide deviations from the nominal tolerance, which were definitely traceable to the inadequacy of the resistor for the application. However, the resistor mounting was so tightly designed that it was almost impossible, without a major operation, to mount the desired replacement resistor, although it was only 1/32 inch longer than the original.

Innumerable other instances may be cited. A few odd cases of trouble may be mentioned in passing, such as the case of the laboratory which in the year A.D. 1952 was still using composition resistors of 1937 vintage; and the case of the guided missile model, in which resistors were used which had been soldered in and out of breadboard models innumerable times; and the case of chronic fires in projection rooms of motion picture theaters traced to prettily cabled wiring with flammable insulation, carefully dressed and draped around power wire-wound resistors operating at nearly 250 degrees C.

These, then, are just a few samples of what happens to resistors—and undoubtedly other components—which cause equipment failure and unreliability. We mount and wire components in almost complete disregard of the possible consequences; we process them in ways which may be destructive, without inquiring as to the effect of such processing on the component; we use minimum space in designing resistor mounts thereby making it difficult, if not impossible, to substitute more reliable parts in the event of trouble; we ignore available technical data and use close tolerance resistors in the hope that they will solve our stability problems; we do not analyze circuitry to anticipate possible troubles and provide protective measures in advance. In brief, we assemble the resistor or component in the circuit and expect it to carry the reliability burden.

These instances of abuse, misuse, and misapplication of components sometimes raise a certain skepticism as to whether reliability is as important as we are led to believe, because the treatment to which these components are sometimes subjected is the direct opposite to that which reliability would dictate. They illustrate quite conclusively that component reliability is not the exclusive responsibility of the component manufacturer, but is equally, if not more so, the responsibility of the component user. What he does to, and with, the component is often the principal determinant of the reliability of his equipment. If due regard were paid by the user to the properties and limitations of components, the incidence of failures would be substantially reduced.

It is interesting to note that this factor has been largely ignored in most of the discussions of component reliability. The component has been considered a thing apart, unrelated to its environment. It is good or bad, depending upon what is in it. This is only part of the story. This attitude ignores a most important factor in the component environment, namely, the human element around it—the research, development, design, and factory engineers. What they do can make a reliable component appear unreliable—witness the cases here cited. Or their actions can make an apparently less reliable component be very reliable by proper use of the component and proper original circuitry design.

This latter is beautifully illustrated in a paper entitled "Rudiments of Good Circuit Design," by N. H. Taylor, of The Massachusetts Institute of Technology, given at the April 1953 Symposium on Component Reliability at Pasadena, Calif. Two designs of flip-flop circuits are described. One, conventional, employing 1 per cent resistors; the other, original, employing 5 per cent resistors and a few more components. The latter had a much greater reliability even though it utilized components which varied over a wider range of values. The important point here is that Mr. Taylor set out to design a more reliable system avoiding the use of close tolerance resistors and using more available and, perhaps, less stable components. All of which leads to the main point of this discussion, namely, objectives.

There are no perfect components, so we must learn to live with what we have. But the choice is great. Also, we have to know what we want when we make this choice. For example, there are at least five different types of  $\frac{1}{2}$ -watt resistors: composition, deposited carbon, boron carbon, metal film, molded wire, and precision wire. Every one of these fills an important need and has its place in the electronic scheme of things. They vary widely in cost, size, range of values, and characteristics. But none of these resistors has everything. The choice must therefore depend on the characteristics of maximum importance. The user-engineer must know his requirements. And this presupposes that he knows the operating conditions in his equipment (which unfortunately is not always the case). With this in mind a choice is made. There is no point in asking for everything, smallest size, low cost, low-temperature coefficient, ability to withstand high temperature, minimum change with time and humidity, etc. There is no such thing. Somewhere a compromise must be made. If the choice is properly made with all the facts at hand, the results should be good. If the results are not good, the choice may not have been correct, or that is the best that can be done in the present state of the art, or the objective of reliability was not uppermost in the mind of the user.

The case of the 1 per cent deposited carbon resistor (Case 2), which changed about 4 per cent under load, illustrates this point fully. If temperature stability were the prime requirement, and such a change were intolerable, the wrong resistor was chosen. This class of resistor is reliable and stable, but it cannot meet this particular requirement. There are resistors that can, but a price would have to be paid either in size or cost or both. If this requirement was paramount in influencing reliability of the equipment, then the price should have been paid. If other factors were predominant, then the resistor should not be condemned as being unreliable for it was doing the job it was designed to do.

A new piece of equipment currently calls for resistors

of the order of magnitude of 50,000 megohms. Apart from certain electrical requirements, there is a size limitation. It must be preferably as small as a  $\frac{1}{2}$ -watt composition resistor, perhaps as large as a 1-watt composition resistor. The size and value practically dictate a composition-type resistor, either solid or film, with the reliability inherent in this class of resistor. If for any reason the equipment did not perform properly because of the expected changes in resistance, it would not be correct to say this resistor was unreliable. It is perfectly reliable within its limitations. Even though reliability was of paramount importance, there is no other choice. We must live with the best compromise available.

A final point—objectives in equipment development and design. What are the objectives usually set forth in a new equipment project? Performance, always—equipment must meet specified performance standards. Most often, space-miniaturization has almost become a fetish. Cost, almost always. These are basic objectives and are always spelled out. No doubt there is some thought of reliability. But how often is reliability spelled out as a prime objective, if not the prime objective, in equipment development? How often is the specification established that above all else the equipment shall not fail, even if it means sacrificing some performance, space and cost? It is the belief of many of us in the component industry that if reliability were established as a basic requirement, equipment engineers would approach this problem differently. They would exercise more care in the assembly of components; they would study the limitations of components more carefully and use them in ways which would not tax them unduly; they would devise systems and circuits, perhaps unorthodox, which would permit use of components with wider tolerance and variations; they would use more and larger components, if necessary, to insure reliability. The burden of responsibility for reliability would then be more equitably divided, and the incidence of unreliability considerably reduced.

## Discussion

**C. T. Schaedel Jr.** (Convair, Fort Worth): In reference to your figure of 200 to 600 ppm, per degree C for deposited carbon resistance, is this positive or negative?

**Mr. Marsten:** Negative.

**H. Rosenberg** (Burroughs Corp.): Applying a duty factor which causes an average dissipation within rating, what is the peak dissipation allowable with standard half-watt, one watt and two watts, 5 per cent and 10 per cent resistance?

**Mr. Marsten:** I presume reference is to composition resistors, and I also suppose this question refers to pulsing or perhaps surge. I can't answer the question. There is a big gap really in the information available on peak power dissipation and it is a gap we hope we're going to fill one of these days.

