

Understanding Dielectric Absorption

Many electronics text books have a short definition of dielectric absorption, and many capacitor manufacturers have written application notes explaining its effects on certain circuits. Yet, it was not until Sencore introduced the LC53 Z Meter in 1979 that the importance of dielectric absorption was fully realized. It was then learned that the D/A got worse with age in certain capacitors. This, in turn, gave a good indicator of the capacitor's future reliability.

What Is Dielectric Absorption?

Dielectric absorption (D/A) is the inability of a capacitor to release all its stored energy, even if a dead short is applied across its leads. D/A is known by many other names, such as battery action, voltage retention, dielectric soak, residual charge, or soakage. As Fig. 1 shows, if a

capacitor is discharged, and then allowed to sit with the leads open, it will regain a percentage of the original voltage. All insulating materials used as dielectrics show this effect. Some capacitors may regain a large percentage of the original charge. Others have such a tiny amount of D/A that the effects can only be detected with highly sophisticated laboratory equipment.

There are two models used to represent this condition. Fig. 2 shows the D/A as a tiny storage battery in parallel with the ideal capacitor. Fig. 3 shows D/A as a resistor and capacitor in parallel with the main capacitance. Fig. 4 shows a more precise model than Fig. 3, since D/A usually has several different time-constants, explaining why some D/A effects take longer to dissipate than others.

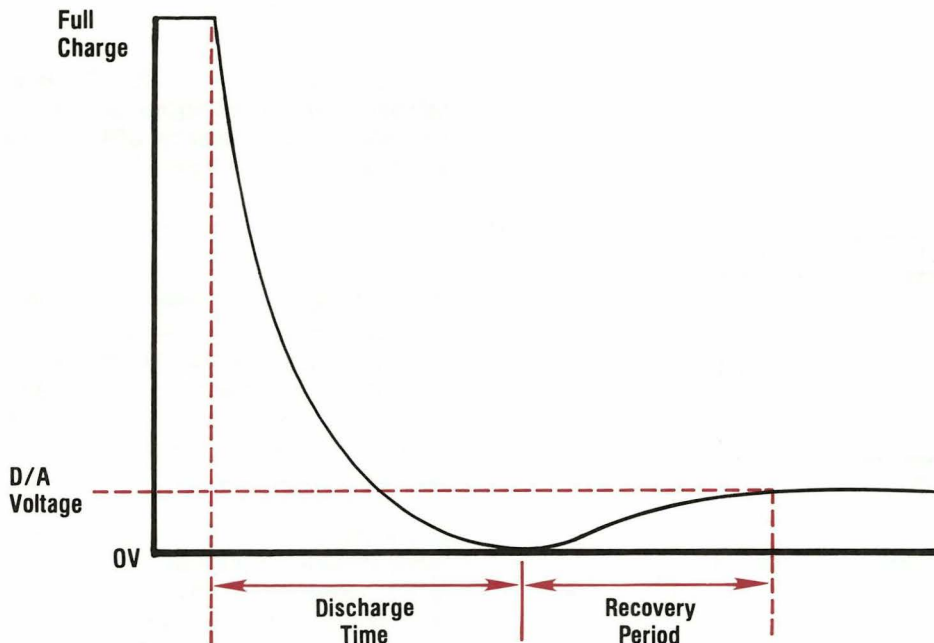


Fig. 1: Dielectric absorption causes a capacitor to recover a percentage of its original charge after being fully discharged through an external path.

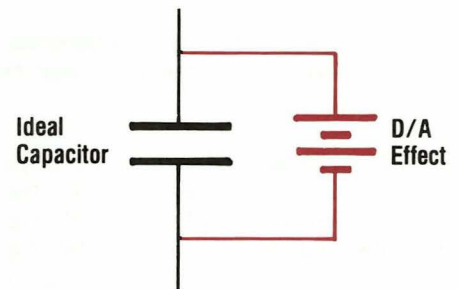


Fig. 2: One way to show D/A is as a tiny storage battery which recharges the capacitor from within.

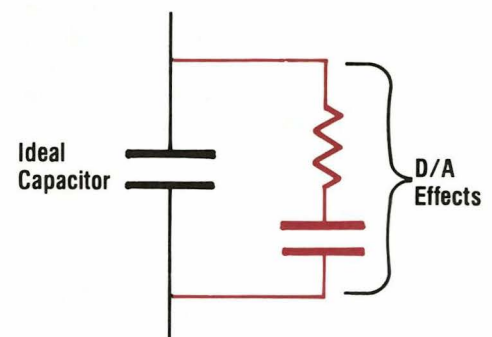


Fig. 3: A more common model uses a resistor/capacitor network in parallel with the ideal capacitor. The D/A portion cannot discharge instantly because of the time constant formed by the series resistor.

How Does D/A Affect Circuits?

Some circuits are directly affected by the effects of D/A. The biggest effects are in circuits that use a capacitor to hold a precise DC voltage level. One example is the reference capacitor in an analog to digital converter (ADC). ADC's are used in meters, level detectors, electronic scales, and any other device which converts a measurement to a digital number. Other critical capacitors are in sample and hold

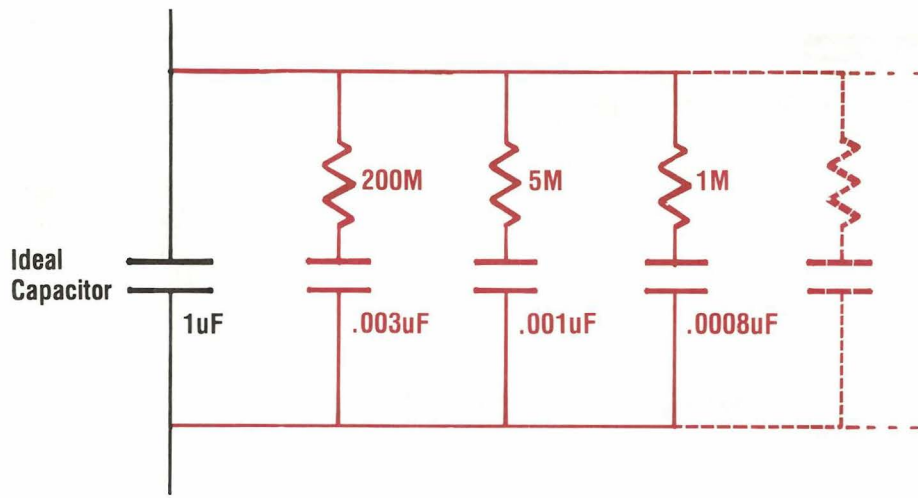


Fig. 4: A more accurate representation of D/A than Fig. 3 uses many different resistor/capacitor combinations to show time constants ranging from seconds to days, in some cases.

circuits, such as AGC, AFT and peak detecting circuits. In either case, the capacitor should charge to a DC level and store the voltage long enough for the remaining circuitry to respond. It should then be discharged, charged to a new level and tested again. With D/A, some previous charge adds to the latest value, causing errors. D/A of 1% may cause trouble in these circuits.

D/A can also affect some series coupling capacitors. The inability to charge and discharge in step with the applied signal causes distortion. These capacitors will tolerate much higher levels of D/A than those in the previous examples, with 5 to 15% being acceptable.

A power supply capacitor may tolerate more than 15% before the circuit is affected. Then, filtering may reduce because the capacitor cannot dump all its charge back into the load fast enough to smooth the ripple.

The best advice is to use the circuit's operation as a guide about how much D/A to accept. If you see circuit troubles which could be explained by extra DC voltage across the capacitor, you may need to replace the capacitor, even though the D/A readings are fairly low. Then, remember to check the replacement capacitor for D/A before putting it into the circuit to prevent installing a bad capacitor.

What Was Known Before The Z METER?

Engineering handbooks, magazine articles and data sheets have been available to help designers choose capacitors with low D/A for critical applications. These references explain that certain ceramic and mylar dielectrics have high D/A, while teflon and polypropylene show low levels. Designers of oil-filled or oil-impregnated, high voltage capacitors, know that they have such high levels of D/A that they are shipped with a shorting wire connected across the terminals to prevent a severe jolt when handled weeks or months after they were tested at their rated voltage.

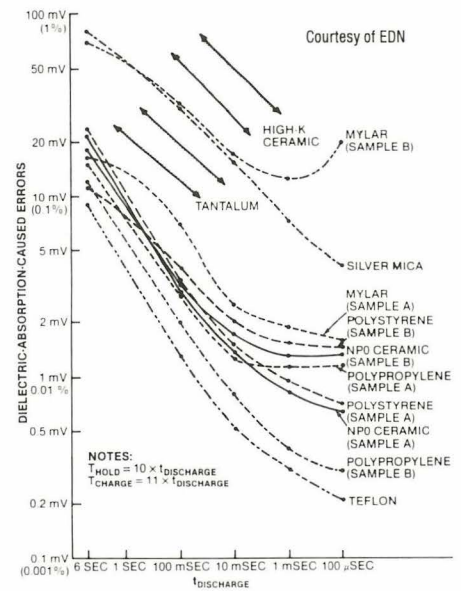


Fig. 6: Before the Z METER, most reference data assumed that D/A would not change once a capacitor with low D/A was selected to use in a circuit.

Most D/A literature assumes that D/A in a capacitor remains at a certain level, so it is only important in choosing the correct type of capacitor while designing a circuit. But, Z METER owners know that D/A sometimes increases and causes circuit problems.

Before the introduction of the Z METER, nearly all the information written about D/A ignored electrolytic capacitors, probably because they have such high levels of D/A that they cannot be used in the critical applications. During early Z METER tests, however, Sencore Application Engineers found that the D/A level is a very good indicator of electrolytic aging. The D/A

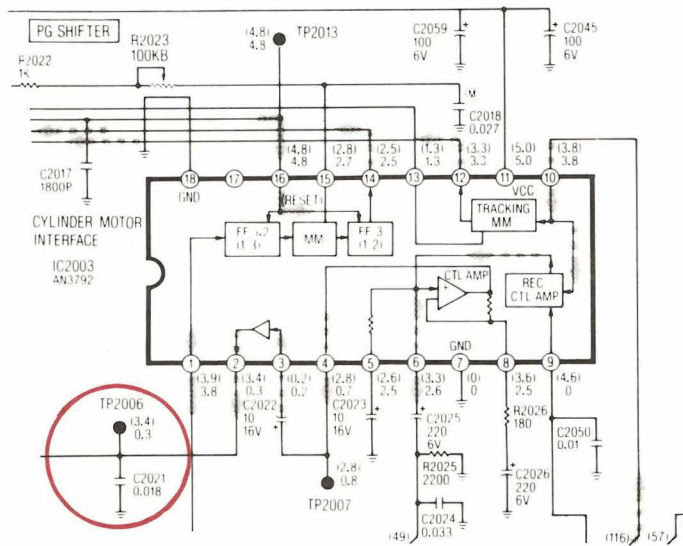


Fig. 5: The DC storage capacitor in a servo circuit is a type of "sample and hold" application which can cause trouble if the voltage from the D/A adds to the correction voltage.

often gets worse before any other measurable changes appear, such as value, leakage, or ESR. Z METER users use this knowledge to pick a good replacement capacitor.

What Causes Dielectric Absorption?

Theory tells us that all the potential energy of a charged capacitor is held in an electrostatic field which causes the dipoles in the dielectric to orient themselves along the lines of force. In real life, however, all dielectrics have some degree of chemical polarity, so some energy is also stored as chemical changes in the dielectric molecules.

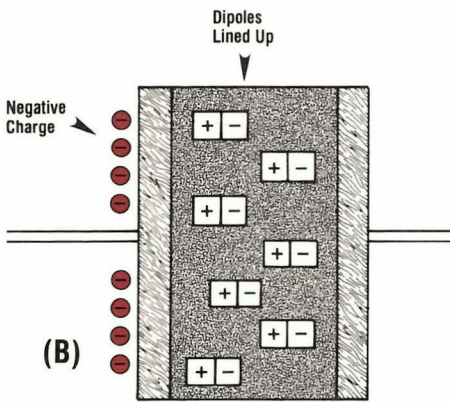
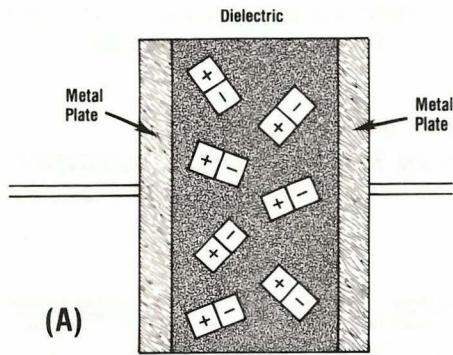


Fig. 7: Charging a capacitor moves the dipoles of the molecules in the dielectric from a random arrangement (A) to a polarized arrangement (B). The dipoles should return to random when discharged.

Capacitor charging happens in two steps, sometimes called "electrification." In the first instant after application of a voltage, an electrostatic field builds between the two plates, causing the dipoles in the dielectric to turn to face the lines of force. These twisted dipoles store energy, compared to the normal uncharged state in which all the dipoles are randomly oriented to produce a net charge of zero.

After this first polarizing process, the dielectric contains two types of electrons: bound and free. The bound electrons saturate the negative plate and the surface of the dielectric. The free electrons move through the dielectric. Free electrons which travel from one plate to the other cause leakage. But, some free electrons

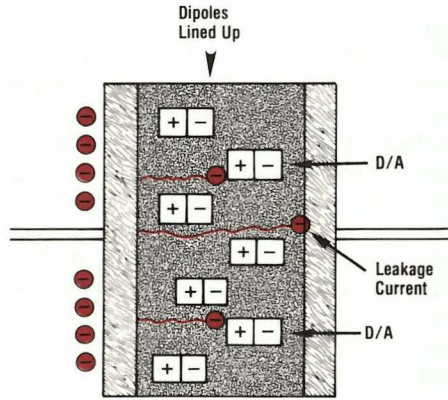


Fig. 8: The free electrons passing through the dielectric cause leakage. The ones which cause dielectric molecules to change state cause D/A.

only move part way through the dielectric, and store energy chemically, similar to the way a storage battery holds energy. These are the electrons responsible for D/A.

D/A is often called "soakage" because the capacitor acts like a sponge. When discharged through an external path, this soakage charge releases very slowly, taking minutes or even weeks in some cases.

What Causes D/A To Get Worse With Time?

This depends on the type of capacitor. A capacitor with a plastic film dielectric often develops D/A if water or chemicals work their way to the dielectric. The contamination displaces the air which normally fills the voids between the metal plates and the dielectric. Since water has a higher D/A factor than, say, mylar, the D/A increases.

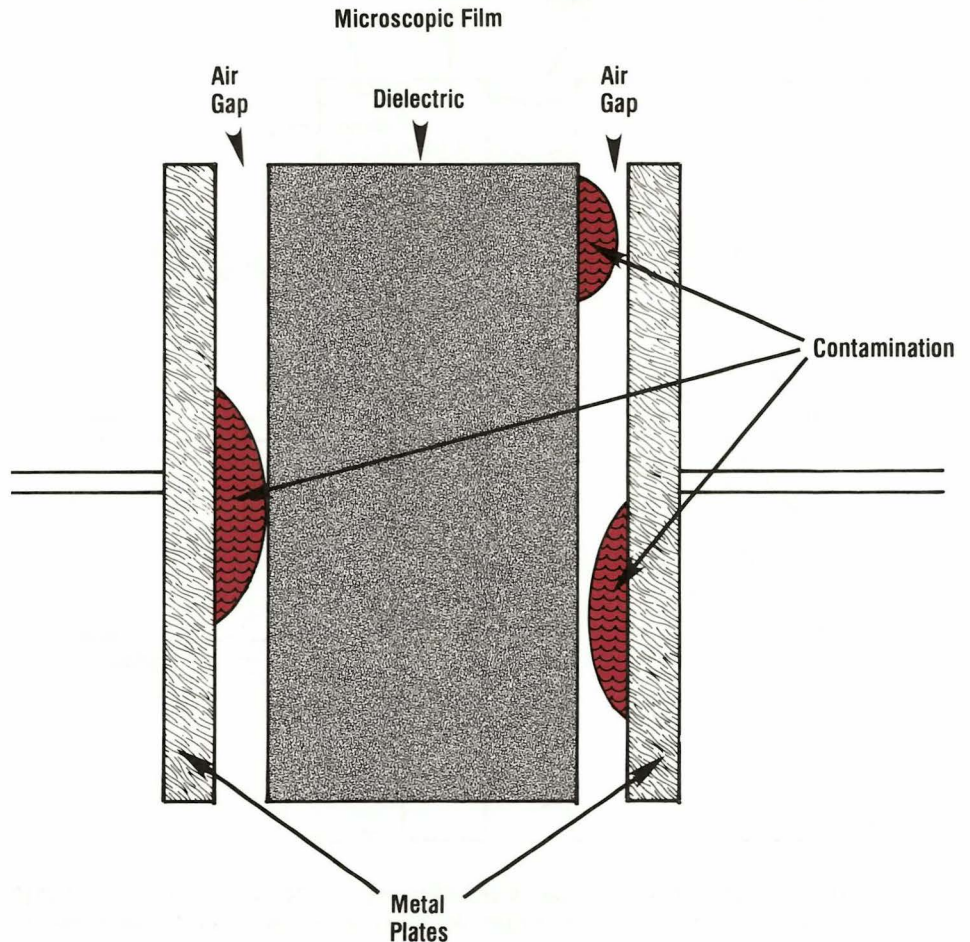


Fig. 9: D/A increase in plastic film capacitors if moisture or chemicals creep in through the seals and fill air pockets between the dielectric and the metal plates.

Moisture also affects electrolytic capacitors, but in the opposite way of the film types. The electrolytic capacitor increases in D/A as the moisture leaves the capacitor. As the electrolyte loses water, some dissolved chemicals may form salt crystals between the paper spacer and the aluminum oxide which serves as the dielectric. These crystals have a higher resistance than the normal (wet) electrolyte solution, causing some parts of the oxide surface to have a series resistance. This series resistance does not cause increased leakage, since the insulating oxide is still intact. It may not cause the ESR reading to increase either, since adjoining sections of the paper may still have enough water to keep the resistance low.

During this drying, the D/A becomes very high because the electrolytic effectively has hundreds of tiny resistor/capacitor networks, all connected in parallel; some with short time constants, and some with long ones. This forms a model very much like the one shown in Fig. 4, which causes high levels of D/A.

Electrolytics will also increase in D/A if chemical changes in the electrolyte solution or in the oxide layer change. Contamination may seep in through the seals and cause the capacitor to have a storage-battery action. This may combine with the drying action to cause even higher D/A levels.

Multi-section electrolytics may also show high levels of D/A if there is leakage between adjacent sections. The leakage acts as a resistor in series with the next section, forming the same model as Fig. 3 shows. The D/A effect changes as the resistance changes. If each section of the capacitor has a different value, the smaller value will show a higher amount of D/A than the larger value. Fig. 11 shows how the D/A from the larger section has a greater effect than the smaller section, as one, then the other is tested.

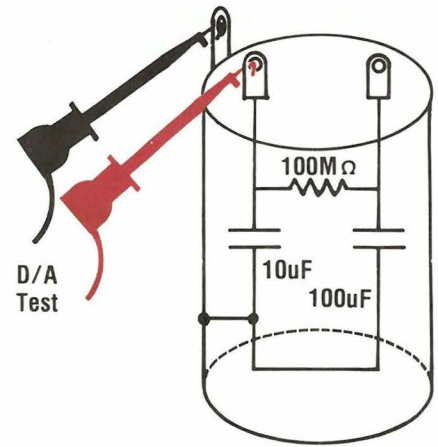


Fig. 11: Leakage between sections of a multi-section electrolytic act like D/A. The smallest value section will appear to have a larger amount of D/A than the others.

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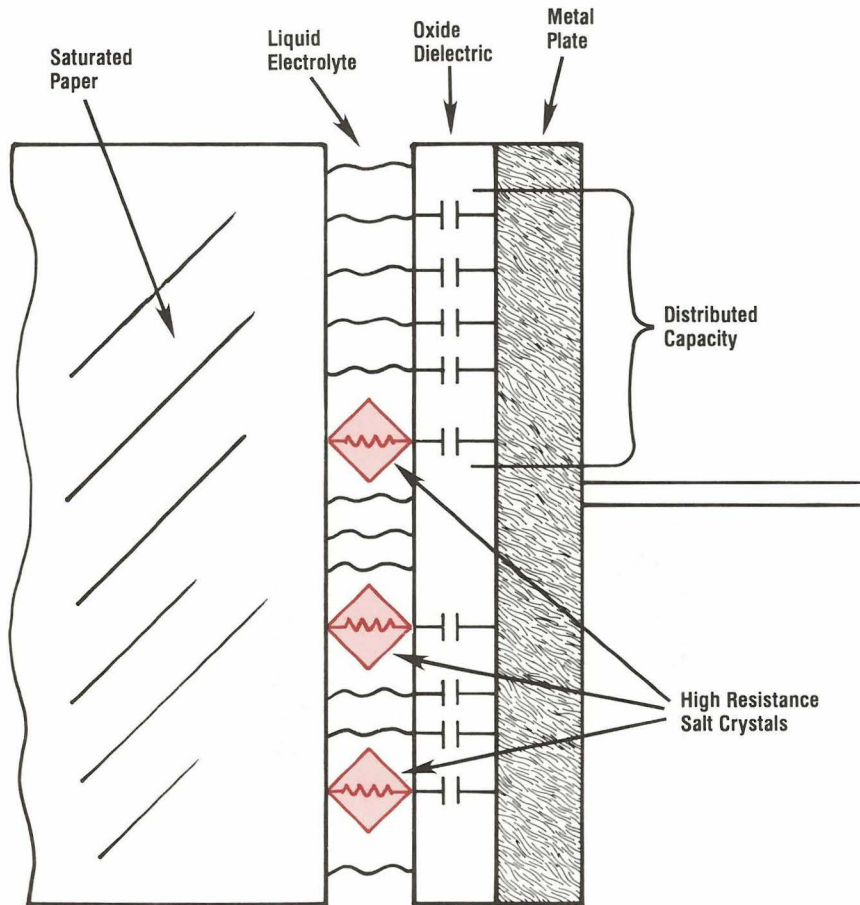


Fig. 10: As an electrolytic dries, some of the chemicals in the paper spacer cause high resistance salt crystals to form. These, in turn, produce a model similar to the one in Fig. 4.