CIRCUIT DESIGNER'S NOTEBOOK

Dielectric Aging Phenomena

Dielectric Aging:

A capacitor's aging characteristic is an important consideration during manufacturing as well as in the end application. Appropriate allowances for this effect must be judiciously accounted for throughout the useful life of the product. This phenomenon is sometimes not regarded by the end user as being critical and can easily lead to circuit performance anomalies.

The term "capacitor aging" describes an effect exhibited by ferroelectric class dielectric materials in which barium titanate ($BaTiO_3$) is the main constituent. A decay in dielectric permittivity, epsilon (ε), is noted over time with these formulations. The aging rate defines an incremental downward change in dielectric permittivity and progresses logarithmically with time. Dielectric aging is typically expressed as a percent per decade hour, i.e., 1-10 hours, 10-100 hours, 100-1000 hours etc.

Dielectric aging is a result of relaxation of the crystalline microstructure of ferroelectric ceramic materials and is initially observed after sintering during room temperature stabilization. Capacitors fabricated with these dielectric materials will exhibit a rapid loss in capacitance value at first, and much more slowly thereafter.

Thus, a change in the dielectric constant, with time is observed during this relaxation period. The dielectric aging phenomena occurs predominantly in ferroelectric ceramic materials and is more prominent with formulations exhibiting high dielectric constants, i.e. EIA class 2 and 3. Therefore, aging rates tend to be somewhat proportional to the dielectric constant or permittivity of a given material. Refer to Table 1 and the example in Figure 1.

Dielectric	Typical Dielectric Constant	Typical Aging Rate
NPO	65	None
X7R	2,000	1.5% - 2.5%
BX	4,000	3% - 4%
Z5U	8,000	4% - 5%
Y5V	10,000	6% - 7%

Table 1: Aging Rates of various EIA Dielectrics.

Note: These are typical aging rates however variations from one commercial formulation to the next may vary significantly.

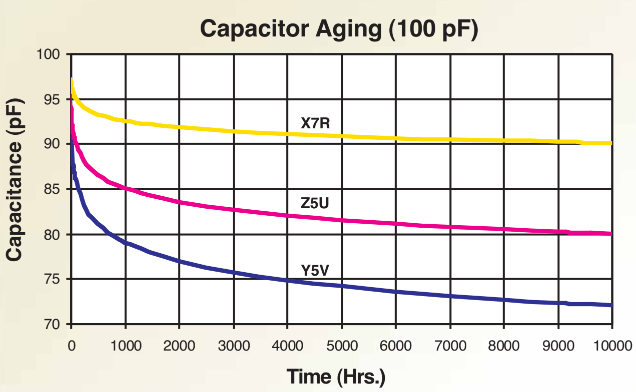
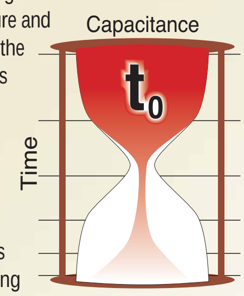


Figure 1: Example of Capacitor Aging – (100pF with various dielectric types).

Curie Temperature:

The Curie temperature is defined, as the point at which an alteration of the crystalline morphology occurs. The crystal structure changes from its initial tetragonal, non-symmetrical configuration below the Curie temperature, to a cubic perovskite symmetrical configuration above the Curie temperature. A sharp increase in dielectric constant (ε) occurs at this temperature. This change in crystalline structure is typical for barium titanate ($BaTiO_3$) formulations and will exhibit a Curie temperature of 120°C. It is interesting to note that the Curie point can be shifted to a higher temperature and or its peak depressed through modifications of the ceramic formulation. Either of these modifications can be produced by the addition of specific additives.



Time zero on the dielectric aging clock starts with the last temperature treatment or heating cycle that exceeds the Curie temperature. This will include various stages in the manufacturing process such as binder burn out, termination, plating, and sintering each of which impose heating the ceramic material above the Curie temperature.

The capacitance is measured approximately 24 hours after chip fabrication, and likewise must be checked again 24 hours subsequent to each heating cycle. This procedure is performed to insure that when the user gets the part, it will have aged sufficiently so that the relative change in capacitance value is reasonably low. Over long periods of time, aging may cause capacitance to drift out of the specified tolerance on the low side. This loss of dielectric constant with time is unavoidable with ferroelectric materials, however it may be restored by re-heating the capacitor. The industry's standard procedure for de-aging a ceramic capacitor is to re-heat the capacitor to a temperature above the Curie point, typically 150°C, for about one hour. This will restore the capacitance back to the original high value at time t_0. Capacitor manufacturers ship parts so they will be well within tolerance after about ten days of aging.

Calculating Aging Rate:

The following formula gives the relationship between the aging rate and the capacitance after time t (hours). C_A is the capacitance you can expect after a given time interval. C_1 is arbitrarily chosen as 1 hour for the purpose of this example but is more commonly given as 24 hours and denotes the initialized capacitance value at time t_0.

$$C_A = C_1 (1 - A/100 \text{ Log}_{10} t)$$

Where:
- C_A = Capacitance after t (hours)
- C_1 = Capacitance at time t_0
- A = Dielectric Aging Constant, (aging rate in percent)
- t = Time from Last Heating in hours

Application Considerations:

Select capacitors with low or no aging rates especially when designing minimum drift applications such as filters, tuning, matching and timing circuits.

Do not specify tight capacitance tolerances when designing ferroelectric class high K capacitors into an application. These capacitors can easily drift out of tolerance over time.

Evaluate the minimum required capacitance taking aging rate as well as temperature coefficient of capacitance (TCC) into account before designing ferroelectric devices into the circuit. This will many times require the designer to specify a guaranteed minimum value (GMV).

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Excerpt from complete Circuit Designers' Notebook, Document #001-927, Rev. E, 1/05