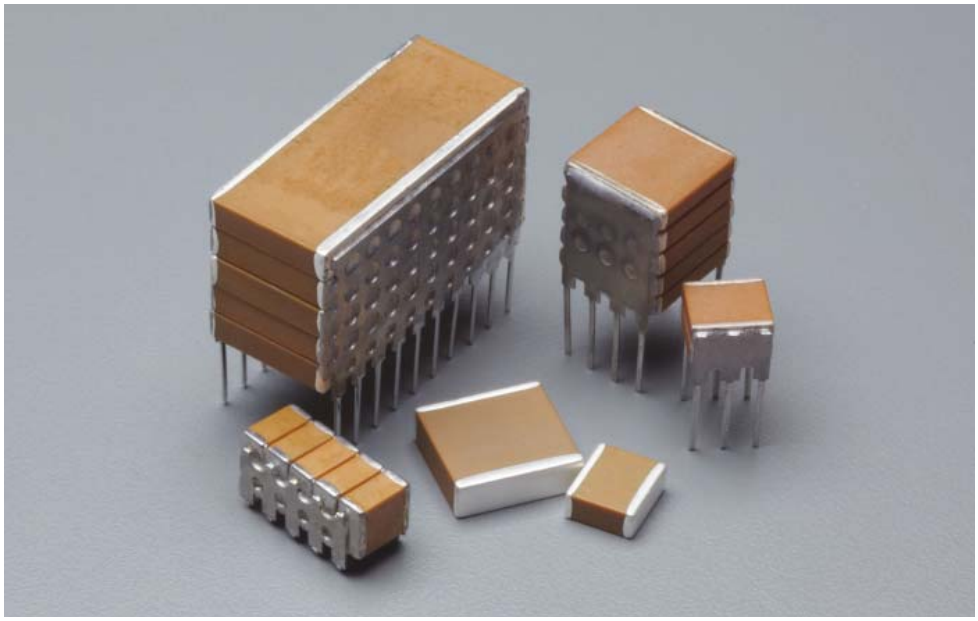
Capacitor Selection for Switch Mode Power Supply Applications



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Application Note

Capacitor Selection for Switch Mode Power Supply Applications

1. Introduction

Faced with the availability of multiple capacitor options for use in high reliability SMPS applications, engineers need to consider performance characteristics and long term reliability when making their selection. This paper provides information related to the more popular choices, including Electrolytic, Tantalum, Film and Ceramic capacitors, compares their key attributes and provides insight and recommendations related to their possible selection for high reliability SMPS applications.

2. Capacitor Options

Electrolytic Capacitors

Often the preferred choice for SMPS applications, electrolytic capacitors offer an extremely high level of capacitance per unit volume at a cost that is typically much lower than alternative designs. Their CV levels are achieved thru a design that employs an extremely thin dielectric material in the form of an oxide layer (Al_2O_3) that is deposited on an aluminum metal foil that has been pre-etched to increase its overall surface area.

Unfortunately, the ability of an electrolytic capacitor to achieve higher capacitance values comes with several drawbacks which often affect their suitability for specific applications:

- A strict adherence to polarity must be always be maintained and failure to do so may result in a catastrophic failure condition

- Electrolytic capacitors exhibit high levels of instability, a gradual loss in capacitance and a significant loss in usable life when operated at higher ambient temperatures

- Operation at lower temperature will also lower the effective capacitance level and the device will exhibit higher levels of dissipation factor and equivalent series resistance (ESR)

- Usage at higher elevations can not only result in operation at a lower ambient temperature but differences in atmospheric pressure between the inside of the capacitor and the outside environment may result in an unintended out gassing of the unit and possible contamination of the system

- Shelf life or inactivity of an electrolytic capacitor in a seemingly benign environment is also a concern inasmuch as the leakage current of the device can increase with time, especially at elevated ambient temperatures

- An inherent aspect of their design, Electrolytic capacitors exhibit a very high level of equivalent series resistance (ESR), especially at higher frequencies. In these applications, an engineer may be forced to place several additional capacitors in parallel

to lower the overall ESR, a requirement that otherwise would not be necessary if he were to choose an alternative low ESR capacitor technology like ceramic.

- Electrolytic capacitors utilize toxic components and materials and as such are not environmentally friendly

Tantalum Capacitors

Tantalum capacitors, which are considered to be part of the electrolytic capacitor family, achieve extremely high levels of capacitance thru the high porosity of its anode structure and resulting large dielectric surface area. Tantalum capacitors are generally considered to have more desirable performance characteristics when compared to aluminum electrolytic alternatives, but their long lead times and higher costs generally limit their usefulness to those applications where size and mass are important and aluminum is not suitable. Other limitations and concerns related to tantalum capacitors would be:

- Like their aluminum counterparts a strict adherence to polarity needs to be maintained otherwise the dielectric will become damaged and the capacitor will fail

- Inherent defects in the dielectric layer and the high oxygen content associated with the cathode material can, in some situations, fuel an exothermic reaction leading to catastrophic failure and in some extreme conditions, a risk of fire. This potential for failure is certainly magnified in those applications where banks of tantalum capacitors are utilized

- Tantalum capacitors exhibit a general intolerance towards excessive charge and discharge currents, especially those of a repetitive nature

- Dielectric thickness constraints generally limit the majority of designs to a maximum working voltage of 50 Vdc at +85ºC and an upper operating temperature rating of +125ºC.

- Use at temperatures above +85ºC generally require a 67% derating of the name plate voltage when operated at +125ºC. Higher voltage ratings and operating temperatures are available, but options are limited and these designs generally require a significant, further reduction in voltage rating and other critical performance characteristics

- ESR values for tantalum capacitors are excessive and can be even higher than that of an equivalent aluminum electrolytic design. This is especially evident at operational frequencies above 100 kHz where microstructural differences in internal resistance can result in a roll off in capacitance by as much as 50%

- Tantalum capacitors utilize materials of a toxic nature and are not considered to be environmentally friendly.

Film Capacitors

Film capacitors generally fall into two basic categories, metallized film and film / foil construction. Metallized film allows for a smaller size, lower mass and a lower cost per microfarad when compared to film / foil and unlike other capacitor types it exhibits the unique ability to self-heal flaws in its dielectric. Film / foil designs are generally intended for higher continuous current applications like a resonant circuit, or a snubber circuit, where there is a high likelihood of transient exposure.

There are a wide range of dielectric materials that can be used for film capacitor design with the most common being polyester and polypropylene. Polyester exhibits a higher dielectric constant and is readily available in a much thinner film gauge than polypropylene, thereby allowing it to achieve a higher volumetric efficiency at a lower cost. Polypropylene on the other hand has a much lower dissipation factor, making it the preferred choice for high voltage / high frequency AC requirements and high current DC applications. Other general characteristics, limitations and potential concerns with film capacitors would be:

- Film capacitors offer a significant improvement in ESR and ESL compared to electrolytic, but are not able to achieve the same levels exhibited by ceramic alternatives

- The maximum operating temperature for polypropylene designs is typically limited to +105ºC which is lower than the generally defined Mil program limit of +125ºC

- Higher voltage ratings comparable with ceramic designs are achievable, but a 50% linear derating of the name plate voltage is required for operation between +85ºC and the maximum operating temperature of the device

- Polyester designs are capable of operation at +125ºC but their high dissipation factor, especially at higher frequencies and their inherent lack of adequate power dissipation, make them generally unsuitable for high frequency, high current AC voltage applications

- For AC applications, a strict adherence to the maximum voltage rating is essential to ensure that corona does not develop in the insulation system, causing the dielectric to carbonize and the device to eventually short circuit

- Allowable temperature rise for film capacitors is generally limited to +15ºC, not to exceed the maximum temperature rating of the device

- Some wet film capacitors utilize toxic materials and may pose an environmental concern

Ceramic Capacitors

Ceramic capacitors characterize a family of capacitors that utilize a variety of different ceramic materials as their dielectric to achieve a wide range of performance characteristics. These dielectrics offer a sizeable assortment of dielectric constants tailored towards specific applications and some of these K values are extremely high in comparison to other capacitor technologies. It is the ability of these materials to achieve a higher K, along with their capability to increase electrode overlap area thru multilayer designs that allow the device to attain reasonable capacitance levels and compete with other technologies on SMPS applications.

The method for manufacturing these type capacitors requires that the device be fired at high temperatures in a ceramic kiln. Once fired, ceramic is characterized as being an extremely strong material in compression, but with limited strength in tension and as such they may be susceptible to damage when exposed to high mechanical stress conditions. In addition, inherent variations in the coefficient of thermal expansion for materials used to manufacture the ceramic capacitors themselves and differences between the capacitor and the substrate to which it is mounted can, in certain situations, make these types of capacitors susceptible to thermal shock. Acknowledging that these potential concerns exist, there are a number of design and process considerations at the engineer's disposal that can greatly reduce the possibility of introducing thermal and / or mechanical shock to the device.

For SMPS applications the ceramic dielectrics most commonly utilized are EIA-STD-198 defined Class II, stable materials. The most common choice is X7R and properties of these materials do present additional performance considerations that the engineer should be aware of as follows:

- Class II materials exhibit piezoelectric characteristics

- Class II dielectrics exhibit a characteristic called aging, whereby the capacitance value measured after exposure to temperatures above the materials Curie point (~ +125ºC) will decay logarithmically with time. Dielectric aging is generally expressed as a percent per decade hour (i.e. 1 – 10 hours, 10 – 100 hours, 100 – 1000 hours, etc.) and typical values for Class II, X7R materials are in the range of 2% or less. Manufacturers will routinely incorporate a design margin that compensates for aging of the device thereby ensuring that capacitance values for delivered product are sufficiently above the minimum allowable value.

- Class II, X7R materials are sensitive to DC voltage whereby the dielectric exhibits a decrease in dielectric constant and subsequent loss in capacitance when exposed to DC bias. The amount by which voltage can affect the capacitance value can be minimized thru a reduction in the allowable volts per mil loading of the device.

- Class II, X7R materials exhibit dissipation factor readings in the 1.5 to 2.5% range and as such may pose a concern when operated in an AC application.

- Taller capacitor stacks, especially those where their height exceeds the minimum base dimension, or those that exhibit significant mass, may be susceptible to damage in high vibration and shock environments. If exposure to these conditions is anticipated, the engineer may want to consider the use multiple smaller capacitor stacks, an alternate design whereby the height is limited and the footprint is increased and / or the use special mounting techniques.

Assuming that the mechanical and thermal shock concerns have been properly addressed, ceramic capacitors offer a number of key advantages when compared to alternative technologies as follows:

- Ceramic capacitors exhibit extremely low levels of ESR, which is especially critical for higher frequency applications and generally allows the design engineer to utilize a lower capacitance value when compared to electrolytic, tantalum or film capacitor options

- Ceramic exhibits comparatively low levels of ESL when compared to other technologies
- Class II, X7R materials are non-polar devices and can be connected in any configuration
- Ceramic capacitors are designed for continuous operation at full rated voltage across their entire operating temperature range
- Ceramic capacitors are maintenance free, non-toxic and environmentally friendly

Performance Summary

Characteristic	Ceramic			Film		Electrolytic	
	NPO	X7R	Y5V	Polyester	Polypropylene	Aluminum	Tantalum
Operating Temperature	-55 to +125°C	-55 to +125°C	-30 to +85°C	-55 to +125°C	-55 to +105°C	-40 to +105°C	-55 to +125°C
Dielectric Constant	15 – 150	600 – 5200	7000 – 22000	3.1 – 3.3	2.1 – 2.3	7 – 10	24
DF	0.10%	2.50%	5%	0.35%	2%	8%	20%
•TC	±30 ppm / °C	±15%	+22 / -82%	±12%	±1%	±10%	±8%
ESR	Excellent	Good	Fair	Fair	Fair	Poor	Poor
ESL	Excellent	Excellent	Good	Fair	Fair	Poor	Poor
Frequency Response	Superior	Excellent	Excellent	Fair	Fair	Poor	Poor
Polar	No	No	No	No	No	Yes	Yes
Environmental Concerns	No	No	No	Yes	Yes	Yes	Yes

3. Summary

Compared to other capacitor options available, ceramic capacitors offer extremely low levels of ESR and ESL and predictable performance characteristics related to temperature, voltage and frequency, making them the preferred choice for high reliability, high frequency SMPS applications. In addition, unlike film and electrolytic options, ceramic capacitors offer a maintenance free environmentally friendly choice.

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