SELECT THE RIGHT PLASTIC FILM CAPACITOR FOR YOUR POWER ELECTRONIC APPLICATIONS

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ABSTRACT

This presentation assists the power electronic designer in selecting the right plastic film capacitor. It reviews the critical characteristics of capacitors utilized in most power electronic applications. It presents why polypropylene is the dielectric of choice and which winding construction is most appropriate for a specific application. It provides several termination methods which improve the capacitor's DV/DT, current carrying, and reliability parameters.

INTRODUCTION

This paper presents the various types of plastic film capacitors which are appropriate for power electronics applications. It reviews the applicable properties of the three widely used dielectrics (ie; Polyester, Polycarbonate, Polypropylene) and the various winding construction methods. It provides numerous termination configurations which can be used depending on the application's requirements and needs. Finally, it discusses the possible usage of special configurations and snubber assemblies where it is advantageous.

Dielectric Choices

Plastic film capacitors have been the capacitors of choice for many power electronics applications because of their inherent low losses, excellent hi-frequency response, low dissipation factor (DF) and low equivalent series resistance (ESR). All of these inherent characteristics are beneficial in power electronic applications. The following will present a review of each of the three most widely used and commercially available plastic film dielectrics, which are: polyester, polycarbonate, and polypropylene.

Polyester:

Polyester has had limited use in power electronic applications, because it's tendency to have higher DF with increasing temperature and frequency. Figures 1 and 2 exhibit the DF versus Temperature and DF versus Frequency, respectively. Note how the DF of polyester increases under both conditions. These characteristics have limited the use of polyester in power applications except where small size is necessary. Since the dielectric constant of polyester is the largest of these three films, and it is available as the thinnest dielectric, both characteristics result in the smallest finished size for a given capacitance value and rated voltage. Polyester can be used in power applications so long as the frequency is low and temperature is near the ambient of 25°C. Polyester has one advantage, its maximum operating temperature of 125°C. This would only be of value in high storage temperature situations since operation at high temperature generates too much heat.

Polycarbonate:

Polycarbonate also has a 125°C maximum operating temperature and provides low DF over the temperature and frequency range; refer to Figures 1 and 2. It can provide tighter capacitance tolerances versus

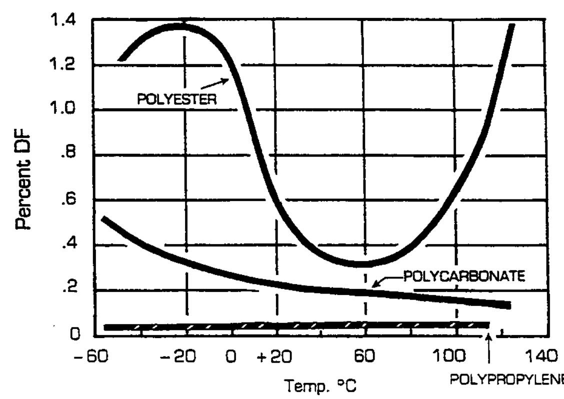

FIG. 1 DF VERSUS TEMPERATURE

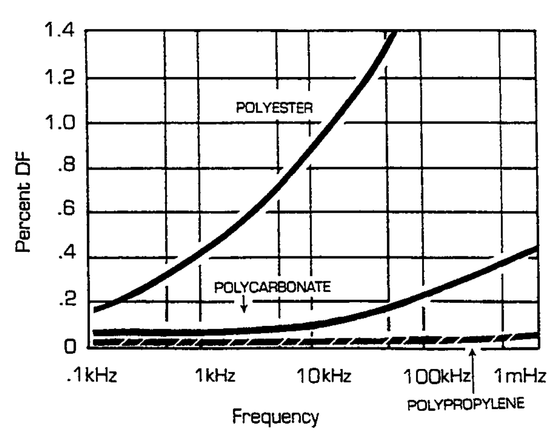

FIG. 2 DF VERSUS FREQUENCY

0-7803-3544-9/96 $5.00 © 1996 IEEE

TABLE I

COMPARISON DATA FOR PLASTIC FILM DIELECTRICS

DIELECTRIC	STANDARD CAPACITANCE TOLERANCES	DISSIPATION FACTOR @ (25°C, 1KHZ)	TEMPERATURE RANGE
Polyester	±5% or greater Typical ±10%	Typical 0.5% Maximum 1.0%	-55°C to +125°C
Polycarbonate	±1% or greater Typical ±10%	Typical 0.1% Maximum 0.3%	-55°C to +125°C
Polypropylene	±1% or greater Typical ±10%	Typical 0.03% Maximum 0.1%	-55°C to +105°C

polyester; see Table I. Polycarbonate has several limitations which limits its use in most power electronics. Polycarbonate, because of reliability problems, is generally available only as metallized winding construction. This limits its DV/DT and high-current carrying capabilities for both peak and rms current. Additionally, of the three widely used plastic films, metallized polycarbonate is the most expensive. At the time of this presentation, polycarbonate's availability needs to be monitored.

Polypropylene:

Polypropylene offers the user many excellent features most needed in power electronic applications. They are as mentioned earlier - inherent low losses, excellent frequency response, very low DF and ESR with temperature and frequency (refer to Figures 1 and 2). It can also provide tighter capacitance tolerance compared to polyester; see Table I. As a result of these characteristics, polypropylene dielectric is the "***Dielectric of Choice***" for power electronics. It's only negative may be its maximum operating temperature of 105°C, since some IGBT junction temperatures can reach the 90°C area. The capacitors are not to be operated like a heat sink, but may as they tend to be mounted closer to the junction on the direct-mount IGBT devices.

Other Dielectrics:

There are several other plastic dielectrics, but none offer the excellent features of polypropylene. They are as follows along with their undesirable characteristics.

Polystyrene: Polystyrene is available only in a film-foil winding construction, which results in poor reliability when compared to other plastic films. It's *low* upper temperature limit of 85°C also limits it's use.

Polyphenylene Sulfide (PPS): PPS, also known as "Ryton",is currently the most feasible dielectric for surface mount film capacitors because of its high temperature capability (150°C operating/260°C short term). It is expensive when compared to other films (3 to 4 times more costly than polypropylene). It is less reliable, and its increasing DF with increasing temperature above 100°C, are major negative features.

Kapton and Teflon: Both are high temperature films capable of temperatures over 200°C. They are very expensive. Both, in most cases, are limited to film-foil winding construction, unless a "metallized carrier" configuration is utilized, where the foil is replaced with a dielectric (generally polycarbonate) with metallization on both sides which acts like a foil. This construction is capable of self-healing (refer to Fig. 5).

Other new plastic dielectrics: New capacitor dielectrics are being introduced, but until they prove themselves and become commercially available at competitive prices they should not be considered. Unless the dielectric or plastic film is utilized in a large volume application other than plastic film capacitor production, it normally does not become a viable dielectric. For example, polyester dielectric is largely available today because of the polyester video tape industry.

Winding Construction

Proper winding construction of the capacitor is as important as the choice of dielectric in power electronic applications. It will significantly influence the current carrying capability of the capacitor, the voltage capability (particularly the AC voltage capability, in assuring AC corona-free operation), physical size of the capacitor, and the capacitor reliability and predominant failure mode. Capacitors will be either metallized or film-foil construction or a combination of each which is identified as a hybrid. The following describes and reviews each of these constructions, with illustrations.

Film-foil:

This was the original type of winding construction, where the conductive plates are separate metal foils (typically tin or aluminum). Today most film-foil capacitors are extended foil construction meaning the foil edges extend out to opposite sides of the capacitor winding. Yet even today, some tab types are used, normally only in small capacitance value inductive-wound capacitors. For power applications, it is not desirable to use a tab constructed film-foil winding.

The foils are offset on either side to create the end margins and foil extensions. The terminations are then bonded to the foil extensions. In some cases, especially with aluminum foil and high current power electronic applications, the foils will be sprayed with a metal end spray to connect all the exposed foil edges. This assures high current carrying capability with high thermal heat transfer, to assist in keeping the capacitor as cool as possible under high current applications. Fig. 3 illustrates the typical single section film-foil construction. With the rather thick foils (normally 6 microns), the film-foil construction provides very high DV/DT and high peak or pulse current capabilities. The film-foil construction does tend to have a lower AC corona inception voltage, because of the larger amounts of entrapped air at the capacitor's foil edge margin locations. Additionally, the typical failure mode will normally be a short circuit, which is undesirable due to the catastrophic condition of failure.

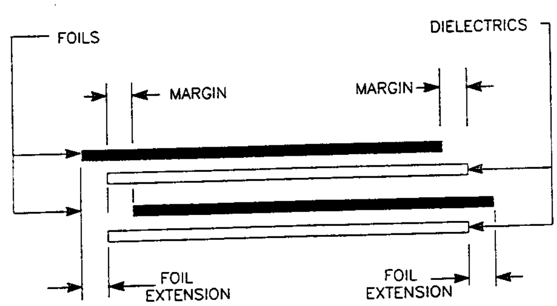

FIG. 3 FILM-FOIL (1 SECTION) WINDING CONSTRUCTION

Metallized:

In the metallized winding construction, the foils of the film-foil capacitor have been replaced with a very thin metallized layer that is vacuum-deposited directly onto the surface of the dielectric. The metallized layer is a few hundred Angstroms in thickness, and is specified as ohms per square. It is measured electricity, by a resistance method. The metal layer is generally aluminum, zinc, or combination of them. See Fig. 4, which illustrates the typical single section metallized construction.

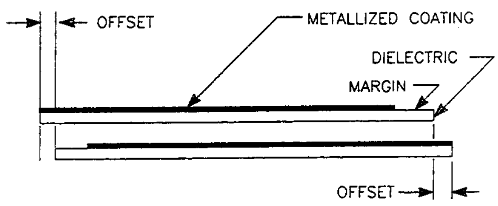

FIG. 4 METALLIZED (1 SECTION) WINDING CONSTRUCTION

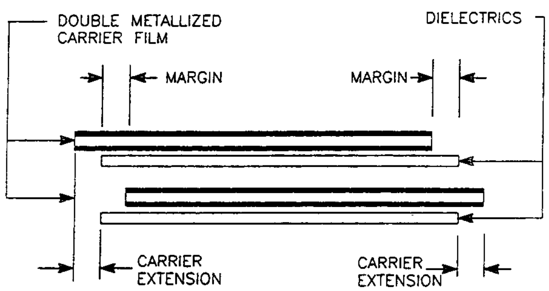

FIG. 5 CARRIER (1 SECTION) WINDING CONSTRUCTION

Since the current carrying metallized layer deposited on the plastic film surface is so thin, the metallized constructed capacitors are limited in their current carrying capability versus the film-foil constructed capacitors. The thin metal layer does offer an improvement in reliability. This thin layer is capable of vaporizing away, if a shorted or weak location occurs in the dielectric somewhere. This condition is known as the "*self-healing*" or "*clearing*" phenomenon. This significantly improves the reliability for transients and over-voltage conditions which would short circuit a film-foil constructed capacitor.

This conductive metallized layer, extending to the ends of the windings, is too thin to be directly bonded to for termination purposes, so a metal end spray is applied to each end of the capacitor. This connects all those thin layers together. By not having a set of foils in the capacitor, the metallized construction provides a smaller size capacitor. The smaller size and thinner conductive plates do limit the current capability, both peak as well as rms current. Since the thin layer tends to have higher DF and ESR values, it tends to over-heat under high rms currents.

This thin metal layer does offer an advantage in AC voltage operation. Since the metal layer is so thin, very little air is entrapped inside the winding; therefore providing a higher AC corona inception voltage versus a film-foil capacitor. Additionally, should the capacitor be operated at AC voltages above corona inception, the failure mode of a shorted condition is greatly reduced versus a film-foil capacitor. The air entrapments in the film-foil construction are generally at the margin and cannot change location. The continuous bombardment of the corona discharges deteriorates the dielectric rather quickly, causing a short. In the metallized construction windings, the air entrapment is small in nature. Where they do occur the corona discharges vaporize or clear away the metallized plate at that location; thereby minimizing the dielectric damage. If the corona bombardment is continuous over a long period of time, the removal of the metallized layer will cause some capacitance loss. This can continue until the capacitor loses all capacitance or reaches open circuit. The open circuit is the typical failure mode for the metallized capacitor. That failure mode is normally more desirable than a short circuit, which is typical for a film-foil capacitor.

Some plastic film dielectrics are not available in metallized construction, as mentioned earlier under other dielectrics. In those cases, the foil can be replaced with a double metallized carrier which will provide the capacitor the improved reliability of the metallized construction, along with its current carrying limitations (refer to Fig. 5).

Hybrid/Film-Foil Metallized Combination:

The hybrid construction offers the advantage of both the film-foil and metallized constructions. It entails the utilization of foil connections to the outside world which provide the high current carrying capability, with a metallized interconnection layer providing the improved reliability of the metallized dielectric because of the self-healing/clearing phenomenon. Fig. 6 illustrates this construction. This capacitor is a two section winding, having two capacitors in series within a single winding. The metallized inter connection layer links the two capacitors together. This offers the advantage of using thinner dielectrics since each capacitor equally shares the voltage (DC, AC, or both). Therefore; it is like having two capacitors in series, so it will be capable of handling twice the AC voltage corona-free.

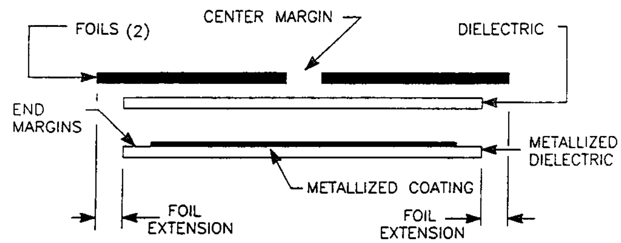

FIG. 6 HYBRID (2 SECTION) WINDING CONSTRUCTION

A disadvantage is that two capacitors in series require that you wind two 2 mfd in series to obtain a 1.0 mfd capacitor for example. This does cause slightly larger size, but allows thinner dielectric (only half voltage). This larger size does provide more end termination to handle the high peak and rms currents, and it is able to dissipate more heat from the capacitor because of the larger size. The improved reliability is provided because the metallized interconnection layer can clear or self-heal should a transient or high over voltage condition occur.

Besides foil, many capacitor manufacturers use a double-sided metallized carrier configuration. Refer to Fig. 7 for an illustration of that construction. The metallization on both sides does improve the current carrying capability, but the foil constructed hybrid is much more robust and superior. ASC Capacitors normally recommends the more robust construction, since it handles higher currents, provides low ESR and DF values, and improves the heat transfer capability of the winding.

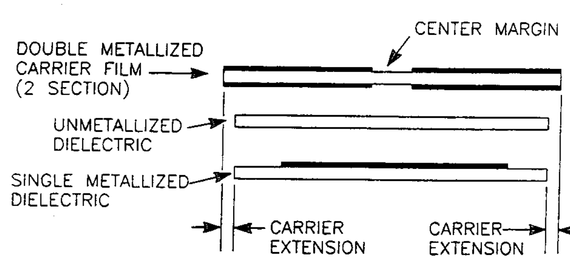

FIG. 7 CARRIER HYBRID (2 SECTION) WINDING CONSTRUCTION

Other combinations and versions are possible should higher AC voltage ratings become necessary. Additionally, capacitor sections can be added with adjustments in size, capacitance value per section, and dielectric thickness consideration. Normally each capacitor section will provide an additional corona-free operation of 250 to 300 VAC, depending on dielectric and winding construction.

Under severe high current or voltage conditions, the metallized interconnection layer may have to be changed to a foil, creating a film-foil two section capacitor. This loses the self-healing/clearing capability and the capacitor can possibly short circuit. Fig. 8 illustrates that construction. This construction is necessary in high current applications

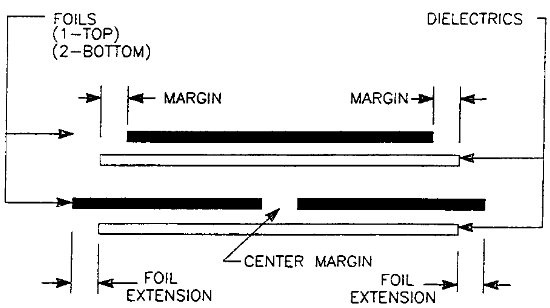

FIG. 8 FILM-FOIL (2 SECTION) WINDING CONSTRUCTION

since the thin metallized layer can only handle so much current before it begins to overheat and possibly shrink in length, drawing the two foils together and causing a shorted condition. The two section series foil-film capacitor normally will only short in one of the two sections which will immediately cause the capacitance to double. The remaining capacitor section now is at a voltage twice its rating and will short out within a period of time, depending on the actual operating conditions.

Terminations

In addition to the dielectric and winding construction, the method of termination between the capacitor and the circuit can influence the capacitor's performance. This is particularly important in power electronic applications because of the high currents and desired low inductance and low ESR. Additionally, by reducing the inductance effects of the terminals, higher resonant frequencies are achieved which may be critical in high capacitance filter applications. The following examines the various methods of termination on printed circuit boards, direct IGBT mount, and point-to-point applications.

Single solid wire [normally 18 AWG or 16 AWG tinned OF (oxygen-free) copper wire].

This is the common printed circuit board (PCB) mounting technique and typical capacitor configuration. By placing the lead egrees near the PCB hole location, a reduction in inductance is achieved.

Multiple-solid wire leads. [tinned OF]

Several leads can be used for greater current carrying capability and mechanical support when attached to the PCB. This is also a common PCB mounting technique with multiple holes and possible use of multiple connections (using capacitor leads as the connector or inter-connection points).

Ribbon or tab leads. [tinned copper]

This method has a much greater current carrying capability and more mechanical support with only a single slot in PCB required. This is uncommon, but easy to PCB mount or for use in point-to-point terminations. They could also surface mount solder the ribbons to PCB.

Bolt down lug or ribbon terminals.

These provide high current and high heat transfer to PCB or point-to-point applications. Additionally a great deal of mechanical strength with bolt down and wave solder over connections is achieved. These terminals can be bolted directly to bus bars for direct-mount applications.

IGBT direct mount lugs.

ASC offers capacitors which can be directly mounted on IGBT's, with 20 to 29mm bolt spacing in three standard versions: step, flat, and gull-wing. See Fig. 9 for details of ASC's 329 and X329 snubber capacitors.

Braid leads.

This type of terminal offers very high current carrying capability with point to point soldered or clamped attachment techniques.

Stranded wire leads.

Stranded wire allows the capacitor to be located any where space is available. Long leads will result in higher DF, ESR, and inductance. They can provide further reliability in a high vibration applications since they tend to be flexible.

Besides these termination techniques, the plastic film type capacitor is more adaptable in special snubber and assembly applications when using a wrap-and-fill encasement. Wrap-and-fill offers a high degree of volumetric efficiency; whereas, a fixed case size normally wastes a portion of their volume. The dimensions can be changed easily and allow modifications in thickness, height or length without retooling another case. ASC's 329 and X329 capacitors are excellent examples of that concept.

Other unique mounting techniques can be used to fit a specific application. Snubber assemblies can be constructed with techniques that utilize fiberglass boards, power diodes, and resistors, where applicable. Many of these components are utilizes for normal special mounted capacitors.

CONCLUSIONS

The best dielectric, or **dielectric of choice** is polypropylene. The low ESR and DF with temperature and frequency make it suitable for power electronic applications. The selection of winding construction will vary depending on the application. For most power electronics, the film-foil metallized polypropylene hybrid is best. The terminations also depend on the application, but the least complex are normally the most cost effective type.

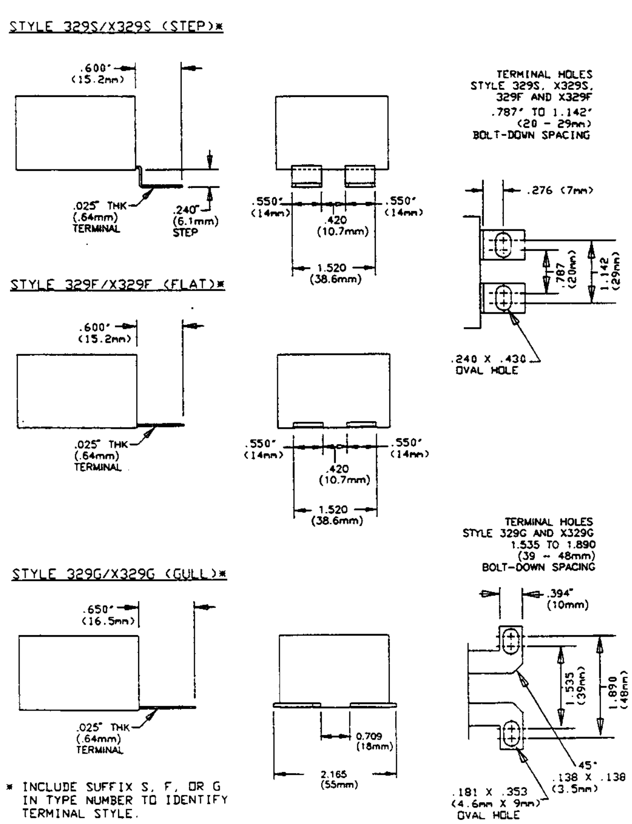

FIG. 9 ICBT DIRECT MOUNT TERMINATIONS