Paktron Division of Illinois Tool Works Inc.
1205 McConville Road, Post Office Box 4539
Lynchburg, Virginia 24502
Telephone 804.239.6941
FAX 804.239.4730

TECHNICAL BULLETIN #12

Reprint from the Proceedings of the 8th Annual
European Capacitor and Resistor Technology Symposium,
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Multilayer Polymer (MLP) Capacitors Provide Low ESR and Are Stable over Wide Temperature and Voltage Ranges

Ian W. Clelland and Rick A. Price

ITW PAKTRON
Illinois Tool Works Incorporated
Lynchburg, Virginia 24502

ABSTRACT

The trend toward miniaturization of electronic equipment has created a large demand for small and low profile components including capacitors. Applications such as ripple current filtering, RFI suppression, resonant matching, pulse decoupling and solid state ignition need miniature capacitors that are low loss, stable and are reliable in DC, AC and quasi-AC environments. The conventional plastic film capacitors historically used in these reliability-sensitive applications are generally too large or not suitable for popular methods of surface mounting. Multilayer Ceramics (MLC's), while size efficient, may not provide the desired electrical characteristics and reliability. A novel but proven capacitor technology is presented which has been built upon the best of the manufacturing techniques of multilayer ceramic and stacked plastic film capacitors. Now film capacitor reliability can be found in chip and block shaped capacitors that approach the board space sizes of X7R, MLC (Ceramic) types. These unique multilayer polymer capacitors (MLP's) offer excellent electrical stability under AC and DC current loads and are not subject to the cracking, shorting or TC mismatch inherent in Ceramic (MLC) capacitor products.

INTRODUCTION

Today, megahertz-range switching power converters are being produced as modular components, replacing their "shoe box" sized predecessors. These high frequency, switching power converters require very small and low ESR capacitors in their low and high pass filter circuits. Card sized data modems, ringer circuits and line terminators require very small and low profile 250 volt suppression capacitors. Modern electronic ballasts require low impedance capacitors in their AC and DC sections and for EMI filtering. RFI filter and ignition capacitors in automotive systems must fit in tight places and be able to withstand harsh environments.

While ceramic and tantalum capacitors are appropriate when applied in small signal or low-to-moderate AC duty cycle applications, care must be taken to avoid catastrophic failures due to increasing bias voltages and ambient temperature changes. In high current and high frequency AC applications both X7R MLC's and tantalum electrolytics suffer from ESR increase and capacitance roll-off. These application induced, parasitic properties of MLC and tantalum capacitor types cause their impedance and ESR to increase drastically from their published, catalog specifications. Under DC bias voltage these capacitor types fall off in capacitance value, causing their impedance and ESR to increase. Under increasing AC voltage, the dissipation factor of MLC types increases causing significant ESR shifts at any operating frequency. The high frequency characteristics of tantalum capacitors are very poor, particularly above 100 kilohertz, limiting their ripple attenuation properties. The multilayer polymer capacitor (MLP) is solving many of these application problems and is providing increased reliability in leading edge technology products. These capacitors are capable of handling tens of amps of ripple current operating near their very high self resonant frequency because of their extremely low reactance, low equivalent series resistance and excellent leakage resistance.

BACKGROUND

By 1984 ITW had developed a new manufacturing system called Interleaf® Technology to miniaturize film capacitor products and bring production throughput to a new level to compete with MLC's. Having had over 20 years experience in ceramic and film capacitor technology, ITW, through its Paktron Division, demonstrated the ability to linearly stack thousands of layers of polymer film in a high volume, production system. By 1985, production volumes of Angstor® leaded, multilayer film capacitors based upon ultra-thin polyethylene teraphthlate dielectric were being sold to the Automotive, Instrument and Industrial markets. A line of surface mount film chip products called Surfilm® was made commercially available and larger power capacitors known as Capstick® were added as a natural extension to the range by 1990. In 1992 the offering of MLP capacitors covered the range from .0047 mfd through 20 mfd with voltages from 50 to 450 VDC. In 1993 the C*V densities were expanded by the implementation of films down to 1.2 and 0.9 micron thickness which allowed substantial improvement in the capacitance (and impedance) per unit volume. Today, this technology is leading in C*V density and is growing most rapidly in the areas of high frequency power conversion, pulse handling and EMI/RFI filtering through the FM band.

INTERLEAF® TECHNOLOGY AND THE FILMS

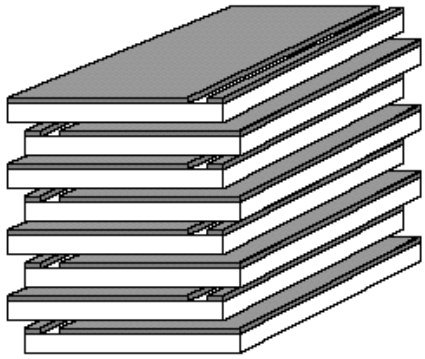


Fig. 1. MLP Multiple Stacking

Several papers have been written describing this production technology and the commonly used dielectric film materials. Refer to Figure 1 for an illustration of the multiple stacking technique used to make the MLP structures. Figure 2 shows a cross section of one of the capacitor sections which highlights similarities to conventional film and MLC constructions. For the purpose of this presentation, we concentrate on new and expanding uses for these miniature and low ESR capacitors which tend to be either high frequency and/or high current applications. The dielectric systems in current use are PET, PEN and PPS. Dielectric selection is based upon the application specific environmental and electrical properties required.

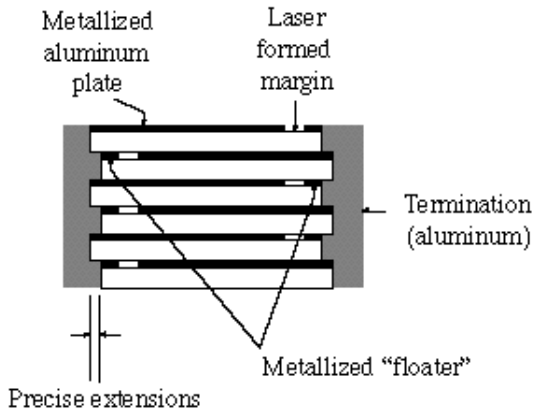


Fig. 2 MLP Cross Section

PET dielectric or Mylar, as produced by duPont, was becoming available at 1.5 micron thickness when the development of Interleaf Technology was underway in the early 1980's. This material is now commercially available down to 0.9 micron thickness (with 0.6 micron in development) which is allowing another major expansion of MLP capacitor capacitance-voltage product. Mylar was selected because of its good electrical characteristics, excellent reliability and ready availability. DuPont has now released PEN dielectric down to 1.5 and 1.35 micron thicknesses. PEN provides increased thermal withstanding for surface mount applications and has very good electrical stability (it is actually more stable than PET). Toray Industries introduced capacitor grade PPS several years ago to address surface mount technology, thermal withstanding needs. PPS is an extremely low loss dielectric, similar to polypropylene and COG Ceramics, which is contributing in several niche applications.

The Interleaf Technology development had several aims, the most important of which were:

- Produce a miniaturized multilayer capacitor
- Solve the problems of existing stacked film systems
- Provide a simplified and low loss metallic connection and termination system
- Find the processes to make surface mount compatible components
- Do all the above in a high volume, cost efficient system

THE RANGE OF MLP PRODUCTS

Refer to the picture in Figure 3 for an illustration on the shape and size of the commercially available MLP capacitors. The single leaded, tape wrapped devices are called Angstor® Capacitors which are available in four lead spacings for convenient mounting. They are rated from 50 to 450 VDC and come in values from .0047 mfd to 3.3mfd. The chips are Surfilm® Capacitors which come in values from .01mfd to

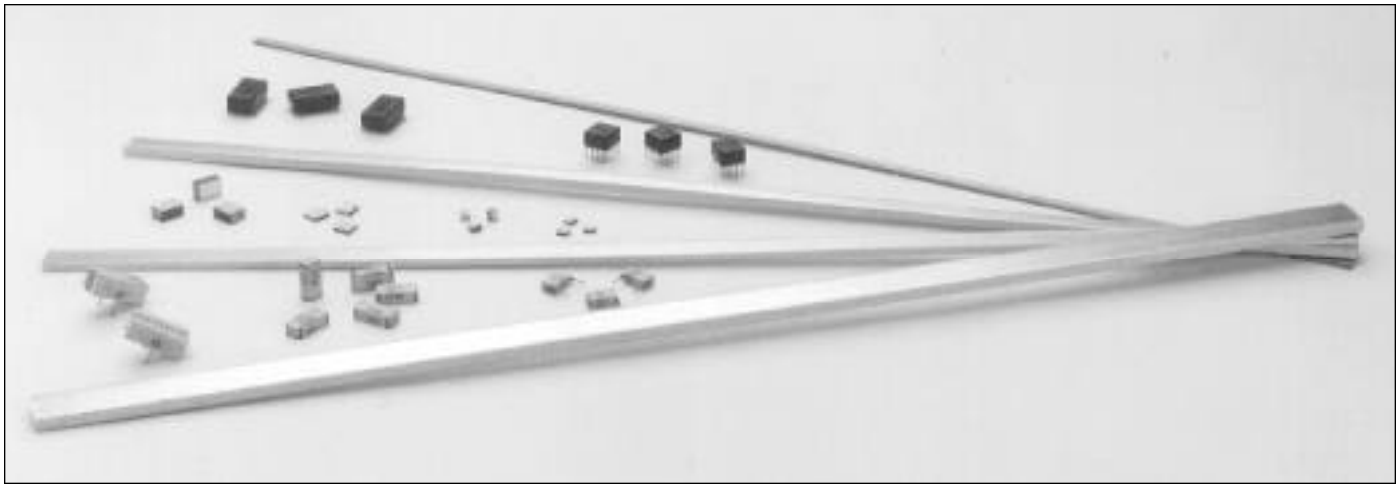


Fig. 3.

2.2 mfd at 25 or 50VDC in standard EIA chip sizes. These are made with various plastic films and are suitable for most reflow soldering systems. The multiple lead framed parts are high value Capstick® Capacitors which are rated from low to high voltage depending upon the nature of the applied peak ripple voltage. Capstick MLP Capacitors are offered from 4.0 mfd to 20.0 mfd at 50/100 VDC for Telecom input voltage systems and from .33 to 1.0 mfd at 400VDC or 250VAC for off-line or power factor correction front-ends. Capsticks may be processed through reflow surface mounting with high yields and have excellent TC matching characteristic with circuit boards which avoids cracking. All these styles have excellent high frequency AC loss factors and make very stable filter, snubber and suppression capacitors in sub-miniature sizes.

HIGH FREQUENCY POWER CONVERSION APPLICATIONS

A most interesting trend in power conversion is the increase in switching frequency to minimize the size of the magnetic and filter components and boost the wattage per unit volume. Driven by portable computers and distributed power approaches in Telecom and Computer systems, switching frequencies have risen from 20 kilohertz to between 400 Khz and 1 megahertz in so-called high density power converters. The filter capacitors have become an important issue as low impedance and equivalent series resistance are needed for reliable high frequency current handling. Because of the urgency of the power conversion industry's design requirements, component suppliers are being mandated the task of supplying high performing, ultra reliable components in smaller package sizes.

LOW PASS FILTERING EXAMPLE

In pulse width modulated (PWM) DC to DC converters, a relatively wide band input filter capacitor is needed. Due to wide use in Telecom systems, the 48 volt DC bus (plus an AC component) filtering is approached with a 100 volt rated electrostatic capacitor. In the illustration (Figure 4), the capacitor acts as a low pass filter to the input ripple voltage, which can be low frequency, and sees the reflected RFI due to the downstream switching noise. The capacitor typically selected is a 4.0 microfarad (PET) Capstick Capacitor with multiple leads for high current handling. This particular capacitor is rated for 11.5 amps ripple at 500 kilohertz under 72 volts peak bias (input) voltage. Shown in Figure 3, is this butt-surface mounted, low profile MLP capacitor with flame retardant coating for this application. It is constructed with over 4000 layers of metallized PET dielectric and high current aluminum terminations which are gathered to multiple lead frames.

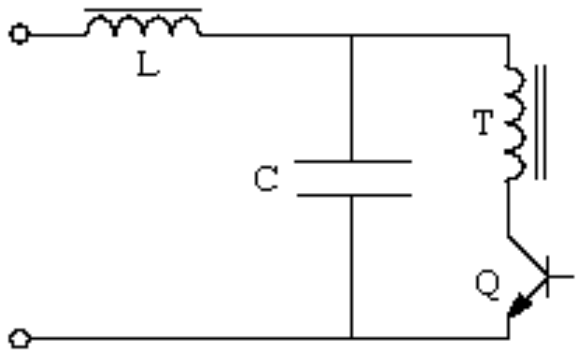


Fig. 4. Low Pass Filter

HIGH VOLTAGE INPUT FILTER APPLICATION

For both quasi-resonant and PWM converters it is very common to encounter 300 volt bus voltage because of its popularity in computer, aerospace and many other applications. The input filter section shown in Figure 5, calls for a 400 VDC capacitor. This again, is a relatively wide band filtering application with special emphasis on high frequency ESR.

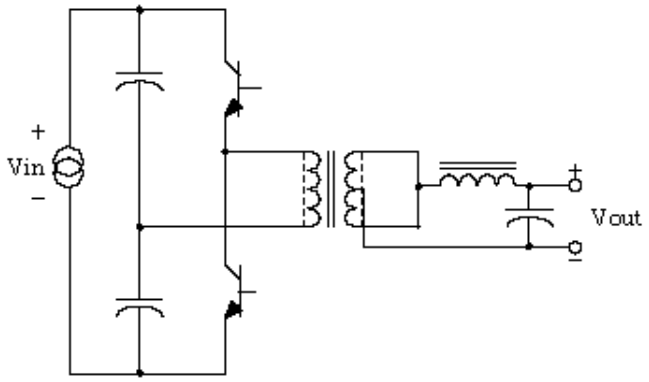


Fig. 5. High Voltage Input Filter

Thick film PET dielectric is used to produce a "gang approach" with leaded Angstor devices or a single Capstick with lead frame. Because of the high bias voltage, the stability of these PET devices over voltage as well as frequency is very desirable. The MLP Capacitors are 10 millimeter, high voltage devices with different mounting styles. All are constructed for low profile and maximum capacitance value per unit volume.

AC AND QUASI AC INPUT EXAMPLE

The growth of power factor corrected inputs and the melding of the high frequency converter back-end with the input circuitry to make a miniature AC to DC converter, have created new approaches to input filtering and voltage conditioning. One example of a growing trend is the "off line converter" using a full bridge rectifier after the bulk input filter. Referring to Figure 6, the rectified AC is filtered by an LC circuit to deliver "clean" voltage to the DC to DC converter section. The capacitor is under the low frequency stress of the input ripple and sees reflected RFI from the switching section. Because of the frequency extremes, the frequency stability of PET is desirable for good ripple attenuation and noise suppression. These universal input capacitors rated to 400 VDC or 250 VAC in 15 millimeter lead spacing. These MLP capacitors are produced using a highly specialized structure resulting in high voltage withstanding and high dv/dt capability.

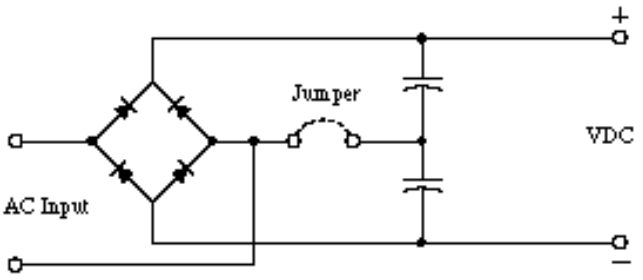


Fig. 6. AC and Quasi AC Input Filter

FREQUENCY MODULATED, RESONANT EXAMPLE

Resonant and quasi-resonant DC to DC converters achieve the highest power densities with good efficiency. There is a big advantage to handling sine wave voltage instead of square wave as it has to do with current handling and filtering. Figure 7 shows the resonant section of a one megahertz resonant converter. For a low voltage output, the circulating current can be very high in the resonant tank. For this application a .1 to .15 microfarad capacitor constructed with PPS is ideal. Polypropylene and COG Ceramics can work in this application but they are large and can be expensive. The capacitor can see in excess of 10 amps RMS at the switching frequency so the low dielectric loss of PPS is desirable here. These 5mm lead spacing PPS capacitors in leaded and surface mount packages are rated from 25 to 400 VDC for various output voltages.

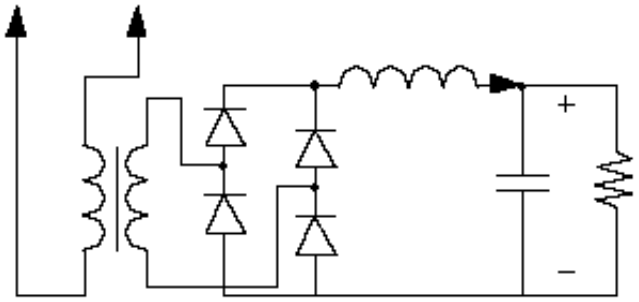


Fig. 7. Resonant Tank Circuit

OUTPUT FILTERING EXAMPLE

For the more popular 5 volt outputs, tantalum electrolytic capacitors are often needed to provide several hundred microfarads for the specified "hold up" of the output. Figure 8 shows the rapidly expanding application of a staged or cascaded output filter. A 10 microfarad Capstick is paralleled with chip tantalum capacitors to reach the desired output impedance and storage. The MLP capacitor will effectively smooth the output ripple voltage at up to one megahertz while the electrolytics provide the continuous output stability. The

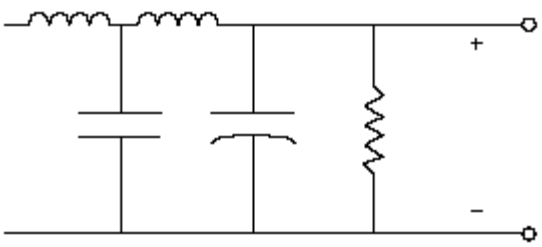


Fig. 8. Output Filter

MLP capacitor used in this application is constructed of over 5000 layers of 1.2 micron PET film and has an ESR of about 3 milliohms at one megahertz. The device is rated at 50 volts which is overkill for the application. In the near future, 0.9 and 0.6 micron PET Capstick parts will be introduced for low voltage outputs. As the MLP's capacitance value increases from 10 to 50 microfarads in this low profile, 10 millimeter package, more of the tantalums can be eliminated. Research is now being conducted toward a low capacitance output filter. The trade-offs of surge impedance and best case transient response are being considered. Work is progressing toward fast control loops within multistage LC output filters

SOLID STATE IGNITION APPLICATIONS

The capacitor-coil ignition approach has been popular for many years in small, two cycle engines and natural gas starters. Legislation is being enacted to decrease the emissions of a variety of industrial and consumer engines. The trend is toward solid state ignitions for all engines including lawn equipment as well as automotive. This classic pulse application can be approached with a high current MLP capacitor designed to handle the high di/dt and relatively high voltage. Ceramics or tantalums are not advised for these applications. Figure 9 shows a typical, ignition circuit. The capacitor, used here, is a 250 volt rated, 15 millimeter device with high current aluminum terminations. The lead wires are plasma welded directly to the aluminum terminations to achieve the lowest resistance connection possible. This MLP capacitor is constructed to emulate the performance of film-foil capacitors which are not used because they are too big for the application. The instantaneous current can be 80 amps in this ignition application.

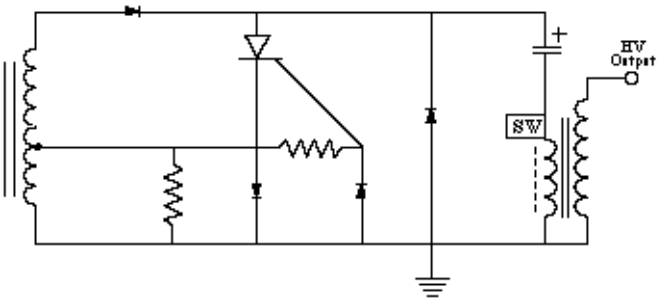


Fig. 9 Solid State Ignition Circuit

RFI FILTERING

Automotive companies have to contend with a low, floating bus voltage while electric motors and actuators pollute the system with RFI and EMI. To protect the radio as well as sensitive electronics most motors and switches are suppressed at the source. This is an ideal application for film capacitors since they are reliable under harsh voltage and current situations. Figure 10 shows a RFI filtering application. The MLP styles are preferred over conventional film capacitors because of their good high frequency characteristics and associated attenuation properties. The PET products are rated at 125°C operation and can withstand the rigors of PBT over-molding in LC modules such as in submersible fuel pumps. PEN and PPS filter capacitors are offered to meet the under the hood operating requirement of around 150°C. All styles are self-encased, providing the smallest possible packaging solution.

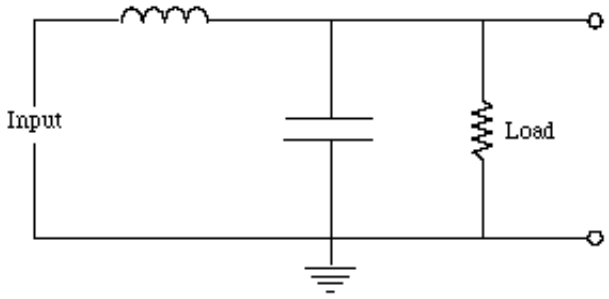


Fig. 10 HF LC Circuit

RFI FILTERING AT LINE VOLTAGE

The growing popularity of incandescent lamp dimmers, ground fault circuit interrupters and electronic ballasts has had a big impact on film capacitor usage. Figure 11 shows a simplified schematic of an RFI capacitor in a chopping lamp dimmer. The metallized MLP capacitor replaced film-foil capacitors originally used in this application with tremendous space savings. The devices are designed for high current carrying and low noise operation. The dissipation factor of these parts is low and predictable at high frequency and they can avoid low frequency hum due to their multilayer construction. Some of the more popular devices range in value from .047 mfd to .47 mfd and are usually rated at 125 or 240 VAC. Similar in construction to the ignition parts, these capacitors handle higher pulse and dv/dt than other film capacitors.

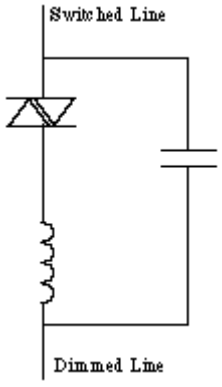
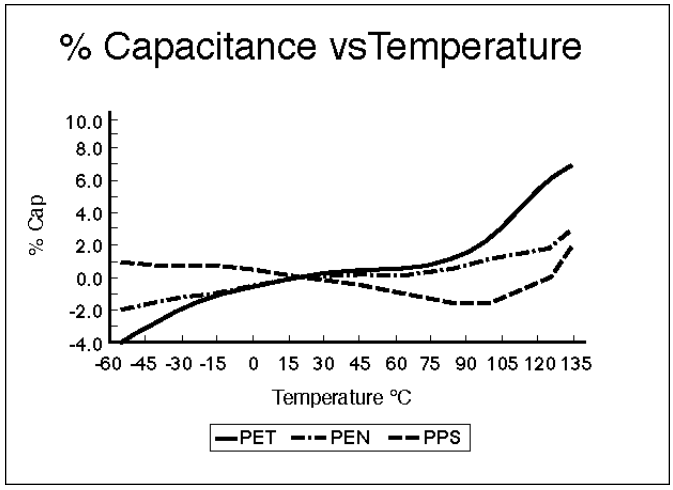


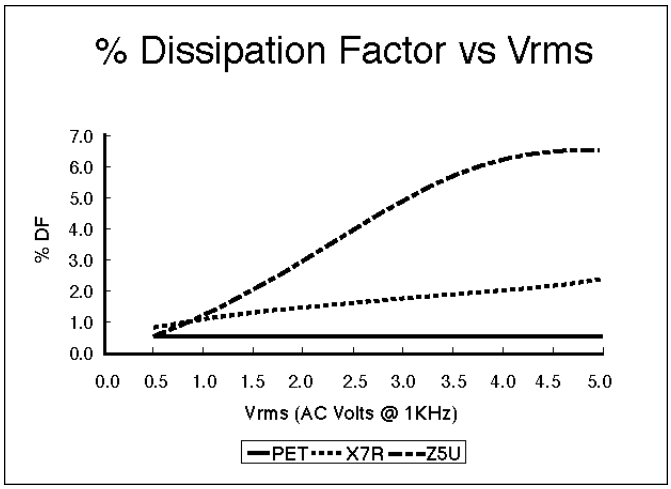
Fig. 11. AC RFI Filter

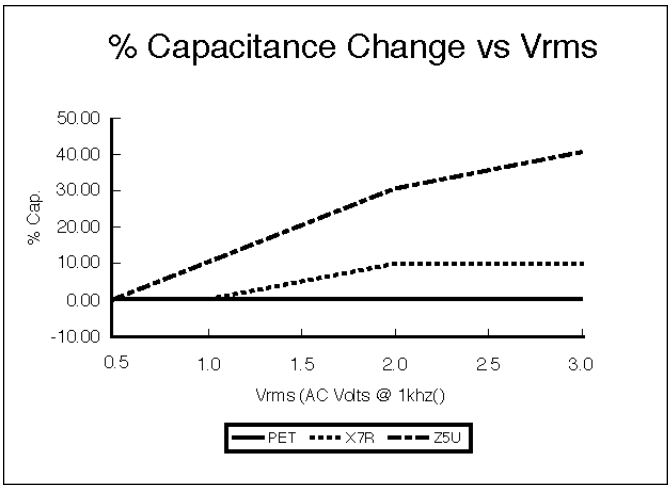
SURFACE MOUNT APPLICATIONS

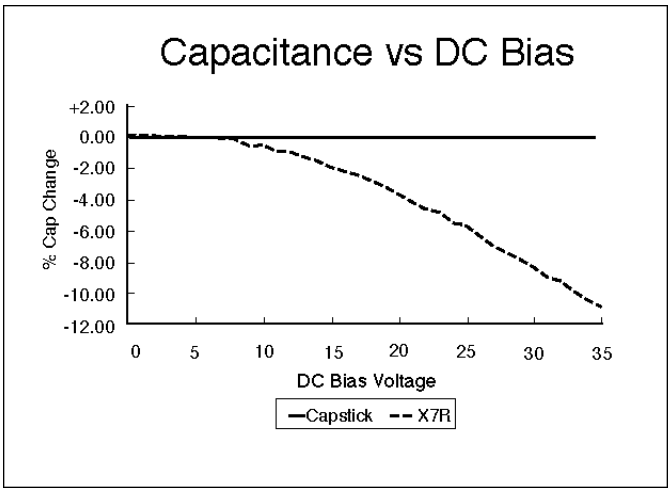
Self encased film chip capacitors are available in the three dielectrics: PET, PEN and PPS. The chip capacitors are available in the standard footprints of 1812, 2824 and 3827 sizes. The PPS chips are replacing other low loss dielectrics such as polypropylene and polycarbonate, which are not practical for use in surface mount applications. Both PPS and PEN chips can be reflow soldered by most popular methods including Infrared Reflow. These series of Surfilm Capacitors are presently limited to low voltage but are being used where close tolerance, low dielectric absorption and frequency and temperature stability is needed. These MLP chip devices have the reliability inherent in film capacitors and are not subject to cracking and shorting problems still encountered with MLC Capacitors. Future efforts will be in the application of thinner films to be size competitive with MLC's and in increasing the working voltages.

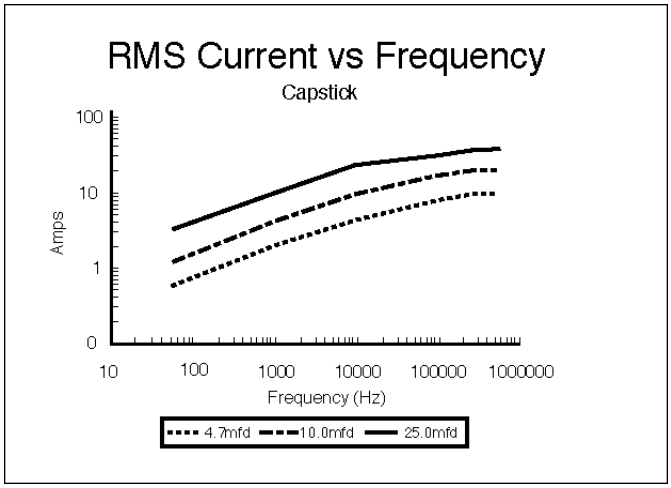
APPENDIX

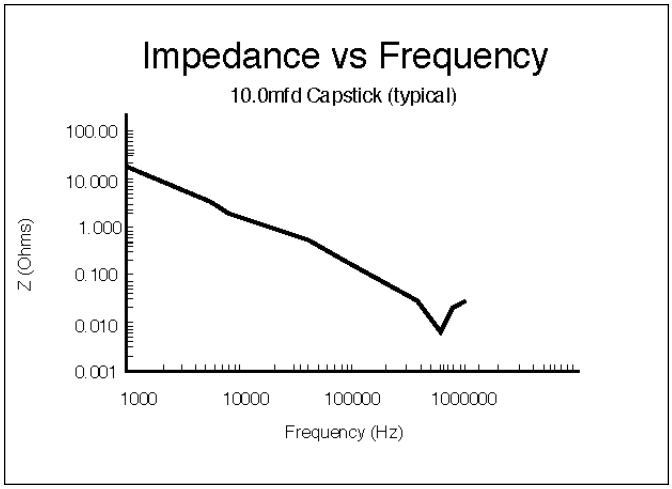


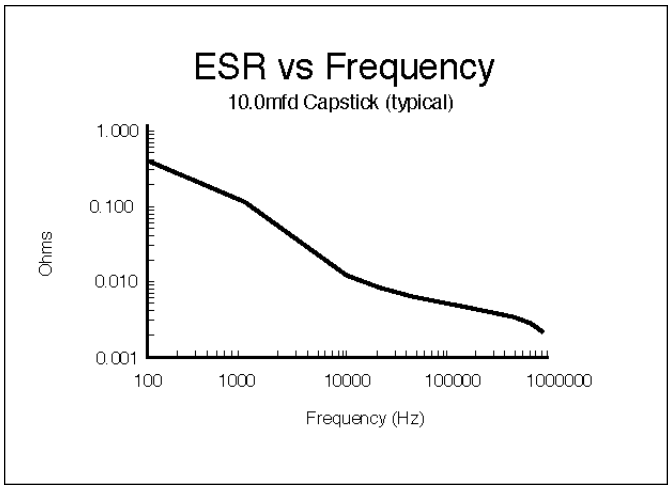












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