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Film Chip Capacitors Save Space in High Frequency Power Trains

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ABSTRACT

The combination of the recent availability of ultra thin polymer dielectrics and advances in multilayer stacking and chip packaging methods has allowed for the production of higher voltage plastic film-chip capacitors which are suitable for surface mounting. These developments have resulted in the highest C*V density, self encased film-chip capacitors available. The film-chip capacitors are extremely stable under application conditions and provide a solution to the single point source of failure found in conventional capacitors under high current conditions. The capacitors feature very low ESR and ESL making them ideal for ripple current filter and reflected RFI capacitors in switching power converters among other high frequency applications.

INTRODUCTION

Any capacitor technology must meet the stringent thermal demands of surface mounting if it expects to participate in the modular power conversion market in the coming years. The continuing trend of increasing switching frequency and expansion of distributed power technology places space, and in particular component height at a premium. Surface mount chip style components are being mandated for new high frequency converter designs. This includes the very low ESR and ESL electrostatic capacitors used in low and high pass filtering applications.

Plastics are generally not considered good surface mount candidates but improvements in polymer films and advances in capacitor processing technology has changed this perception. Both new and mature polymer films are being used to make very low impedance, miniature capacitors which are ideally suited for high frequency ripple current and switching noise filters in mega-hertz frequency switching converters. These Multilayer Polymer (MLP rather than MLC) Capacitors are really a construction hybrid between stacked plastic film and ceramic dielectric capacitors. They exhibit the electrode clearing capability and graceful aging mechanism of metallized film capacitors while meeting the high frequency ESR and ESL attributes of multilayer ceramic capacitors. These MLP film-chip capacitors can also increase system reliability because of their parametric stability, particularly at higher voltage and power levels.

This paper intends to highlight these unique multilayer polymer capacitors, concentrating on those miniature types suitable for surface mounting. Actual application parameters are discussed as well as the latest experience covering surface mounting considerations for the user.

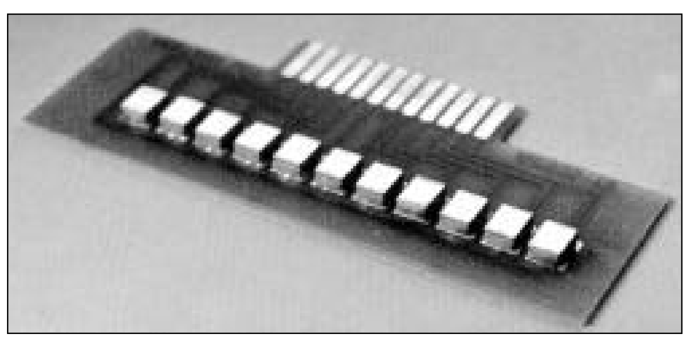

Fig. 1. Picture of Reflowed Soldered MLP Chip Capacitors

BACKGROUND

The use of lead frames as the termination media for both MLC and MLP chips has been found to be highly advantageous because this method produces simple, low impedance connections while also providing stress relief during reflow soldering. The standoff provided by the formed lead frame pins allows for more effective board cleaning and avoids entrapment of solids under the part. Most “large” value multilayer capacitor chips are being made with lead frames in order to carry large ripple currents at high frequency.

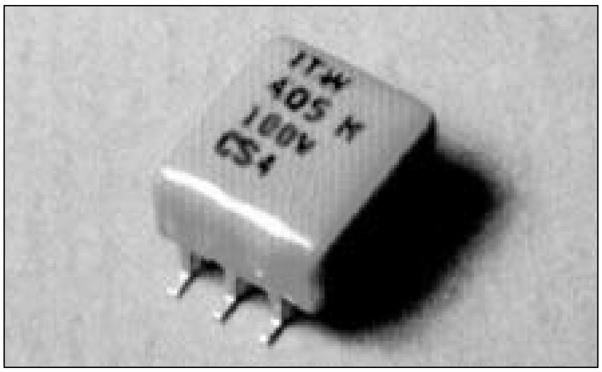

Figure 2 Picture of lead framed, gull winged MLP capacitor

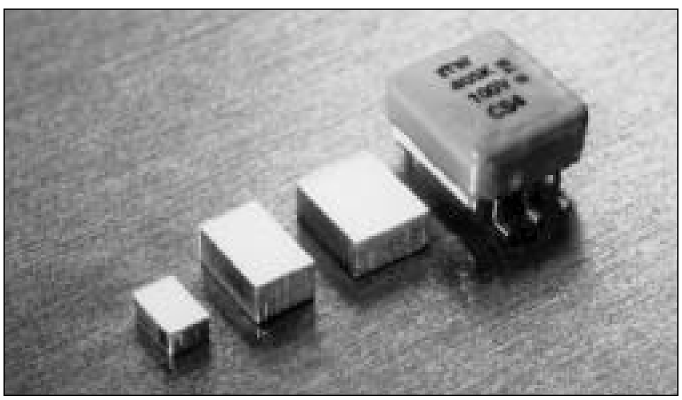

Figure 3 Picture of Chip and Lead framed MLP Capacitors

While lead framed units are currently in broad use, to reach the lowest possible profile the devices must be made in true chip form. This poses difficulty with MLC Chips since the TC mismatch (thermal coefficient of expansion) between the body of the part and the circuit board materials can cause cracking in the larger chip sizes. This TC mismatch does not exist in the MLP capacitor style since the body of the capacitor is plastic and its thermal coefficient of expansion closely matches the physical elongation and shrinkage of popular circuit boards. MLP capacitors are now available as true leadless chips, constructed with polymers specifically engineered and processed for this type of application along with lead-free (Pb-free) tin based reflow solderable terminals. The application of newer films and improved processing techniques has also provided for expanded voltage capabilities in the newer miniature chip capacitors. Of primary interest here is the ability to rate ultra thin polymer film at 100 volts for use in telecom bus voltage applications.

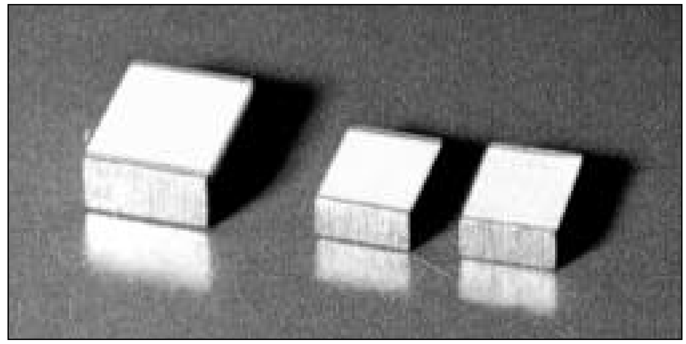

Figure 4 Picture of MLP Chip Capacitors

THERMALLY STABILIZED POLYMER DIELECTRICS FOR SMT

PET (polyester) is a stable dielectric which is finding increased use due to improvements made to the ultra-thin film in combination with advances in packaging technology. PET still offers the highest C*V density of all the polymer films available and is now manufactured in sub-micron thickness. A popular application is in the input/RFI filter section of DC to DC converters where both the di/dt and voltage can be relatively high. This technology is also the preferred choice for higher voltage output filtering at 24 or 48 volts. Future application will be found in low voltage output ripple filters as the thinner films are applied and capacitance values per unit volume increase. *Ref 1.*

While PET is an outstanding general purpose dielectric, PPS (polyphenylene sulfide) is an ultra low loss material suitable for resonant matching and other high current applications. Utilizing these and other new developments, surface mountable plastic film capacitors are envisioned to span the common voltage bus requirements up to 400 volts (from telecom bus voltage through rectified off-line voltages).

Polymer dielectrics would tend to shrink and fail under most reflow soldering conditions if they were not thermally pre-conditioned. The proprietary technology employed by ITW Paktron produces high density polymer laminates which are thermally hardened to be physically stable at reflow soldering temperatures. As long as the established maximum reflow temperature is not exceeded, these devices have been found to be readily surface mountable.

BASIC ELECTRICAL PERFORMANCE OF THE MLP CAPACITOR

The MLP style capacitor employs metallized electrode construction. These electrode plates are composed of 100-200 angstroms of vapor deposited base metal resulting in 1.0-5.0

ohms/square of plate resistance (100 angstroms = 0.0000003937"). The Interleaf® Technology construction overcomes the "high" surface resistivity of the deposited aluminum electrodes by stacking thousands of layers of plate resistance in parallel thereby producing an extremely low effective total resistance (R_t) for the capacitor (typically under 10 milliohms).

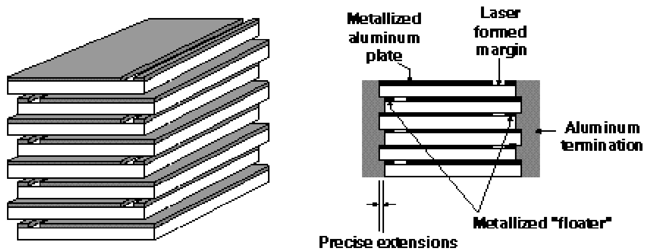

Fig. 5 Internal Structure of MLP Capacitor

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \frac{1}{R_5} + \ldots + \frac{1}{R_N}$$

The stacking of thousands of layers of very thin film dielectric also allows for the production of relatively high capacitance values and associated high current ratings in small package sizes. The film chip capacitors are thermally treated under pressure while in a semi-finished "stick capacitor" form so the finished units may be surface mounted at high reflow temperatures (typically 220° Celsius).

The electrical performance of the MLP capacitor series can best be illustrated with a 1.0 microfarad, 100 volt rated, true chip device. The dissipation factor of this capacitor is typically 0.6% at one kilohertz (Q = 1/0.006) and the ESR is under 10 milliohms at one megahertz.

Because of the very low dissipation factor, the ESR is well controlled for a small, one microfarad capacitor from 100

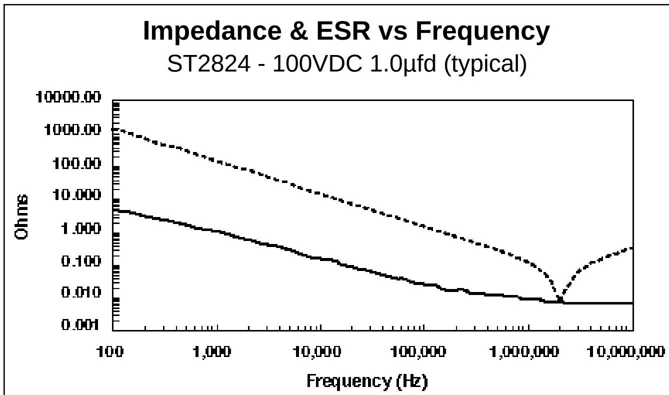

Figure 6

kilohertz through the switching noise harmonics range to at least 10 megahertz. This means the attenuation property of the device will be excellent and the I^2R losses predictably low. The multilayer construction and small surface mount size keeps ESL at a minimum as can be noted on the impedance graph above. The interpretation of this graph is interesting as it is a measurement of the external electric field created by the terminal spacing of the chip capacitor. Some simple back-planing can help counter this parasitic inductance and the high frequency impedance can be made to appear flatter. In other words, the self resonant frequency and inductive reactance will be dependent upon the physical topology.

The selection of polymer films as the dielectric as opposed to ferro-electric ceramics also adds stability under actual operating conditions. The common problems of value aging, capacitance roll-off, capacitance drop under voltage, and ESR rise under AC conditions do not occur in this system. As a result there is far less need for large voltage and current derating practices. The thin film electrode system also avoids the catastrophic shorting failure mechanism found in the thick metal electrode systems of ceramic capacitors.

INHERENT STABILITY

The graph in Figure 7 shows the capacitance stability with frequency for the MLP style capacitor. Unlike capacitors made under other material technologies, the capacitance value of an MLP capacitor does not suffer from significant "roll-off" with increasing frequency.

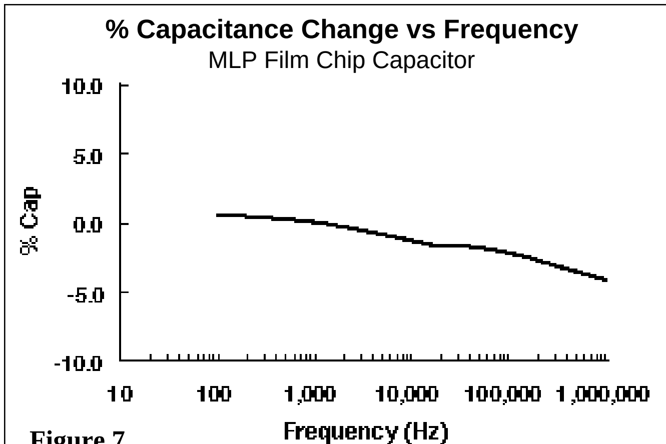

Figure 7

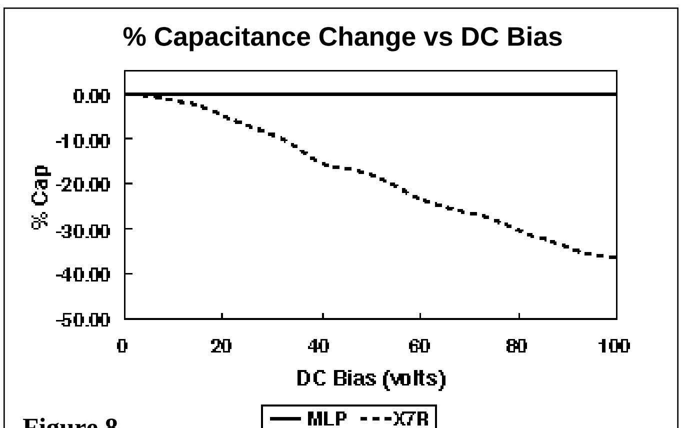

Figure 8

The graph in Figure 8 shows capacitance stability under DC bias voltage of this series of “Multilayer-Polymer Capacitors” compared to the most popular semi-stable X7R ceramic type.

The graph in Figure 9 shows how MLP and ceramic type capacitors react under AC ripple. The derating conventions are drastically different between the two systems since the polymer based dielectrics do not suffer from a voltage coefficient problem.

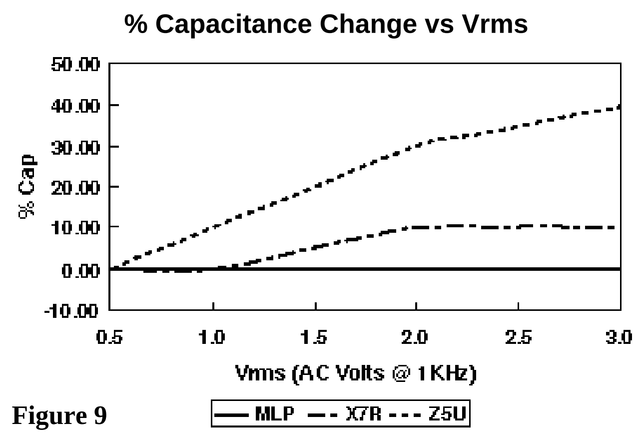

Figure 9

To further illustrate stability under operating conditions, Figure 10 shows the dissipation factor (DF or AC loss factor) shift of the polymer capacitor versus ceramic types under increasing ripple voltage. Even a relatively minor AC voltage increase causes ceramics to increase in dissipation which adversely effects ESR and current handling. Combinations of AC and DC voltages are found in power conversion filter circuits, and a significant advantage in the application of polymer chip capacitors is excellent stability under various power loads and avoidance of special derating practices. Generally speaking, the higher the voltage and total power, the greater this advantage becomes. This is one of the primary reasons the extended voltage multilayer film chip capacitors were developed.

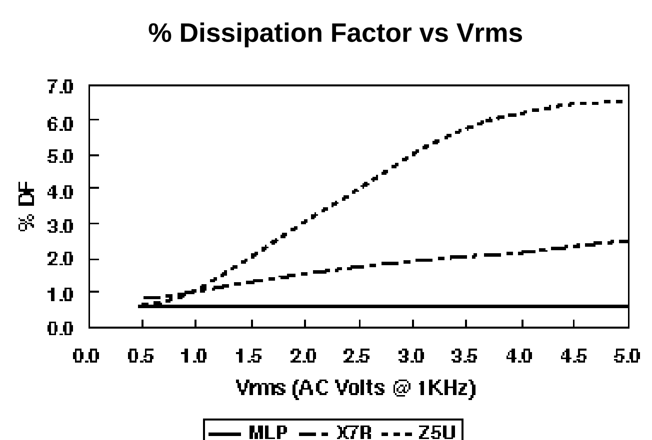

Figure 10

CURRENT AND POWER HANDLING

Please note that the catalog specified ESR is valid under combinations of DC bias and AC ripple conditions as shown in the charts. The ESR is directly related to the dissipation factor (% energy dissipation) and the capacitance value. These attributes are stable under AC and DC conditions which allows the devices to sink relatively high ripple current. The amount of ripple current which can be handled is dictated by the series resistance and impedance at a given frequency. Given some simple rules for allowable power dissipation and internal heat rise, the following table shows ripple current capability in amperes for a sample range of 100 volt MLP style capacitors. All parts shown are surface mount types, the two smaller devices are chip style while the larger devices are lead framed (LF).

Ripple Current Capability (500KHz)

Cap Value	Case Style	Irms
1.0 µfds	SMT - Chip	3.8
2.2 µfds	SMT - Chip	5.2
4.7 µfds	SMT - LF	12.2
10.0 µfds	SMT - LF	15.3

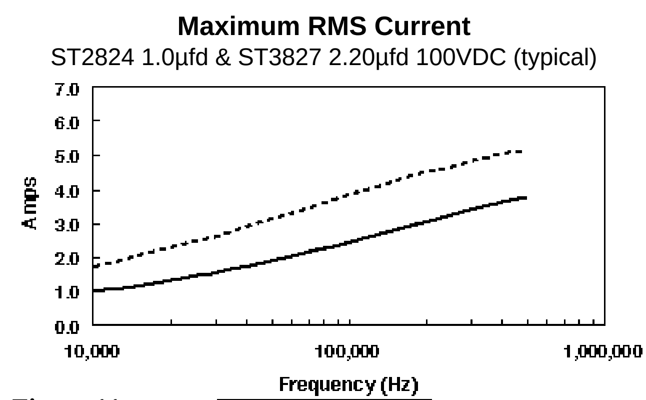

Figure 11

As can be seen in the above table, MLP style capacitors excel in their current handling capability vs. relative size. Because of their low impedance and high load current capability, MLP style capacitors are commonly used as output filters. For example, testing has shown that the 2.2µfd chip can support up to 3.5 amps load current which at one megahertz is more than enough to drive the load through the off cycle. *Ref2*.

An important application is in the output filtering of the popular (48, 72 and higher) supply voltages. At these voltage levels tantalum capacitors are rather large and unreliable while X7R ceramics roll off due to the DC bias component. As shown in the table in Figure 7, a single 2.2 µfd MLP chip provides 2500 micro-joules energy storage at a 48 volt output. This energy storage at 48 volts is the same as a bank of 200 µfd (2 x 100 µfd) tantalum capacitors at 5 volts which also equates to 2500 micro-joules. The problem of transient response and surge impedance of low capacitance, ultra low ESR output filters is left to the control loop designer. In all cases, the higher the switching frequency the more practical this approach becomes.

Capacitance (µfd)	Applied Voltage (VDC)	Energy (µJoules)
1.0	70.7	2500
2.2	47.7	2500
5.0	31.6	2500
10.0	22.4	2500
25.0	14.1	2500
100.0	7.1	2500
200.0	5.0	2500

Figure 12

SURFACE MOUNTING CONSIDERATIONS

After ten years developing this capacitor system, the materials and processes have been refined to produce reflow solderable film chip capacitors. These SMT units are conditioned to withstand vapor phase, convection, conduction or infrared reflow provided the following guidelines are followed.

1. The maximum reflow temperature needs to be maintained at 220° Celsius for a duration less than two minutes in the hot zone.

2. The units should be stored in the moisture resistant packaging to avoid surface moisture absorption until ready for use.

When following these guidelines, there will be minimal capacitance drop and essentially no other changes in electrical parameters.

Using test boards like that shown in Figure 1 and an IR reflow solder profile as shown in Figure 13, the data tables in Figures 15 and 16 represent testing done on the usability of MLP capacitors when board attached using infrared reflow.

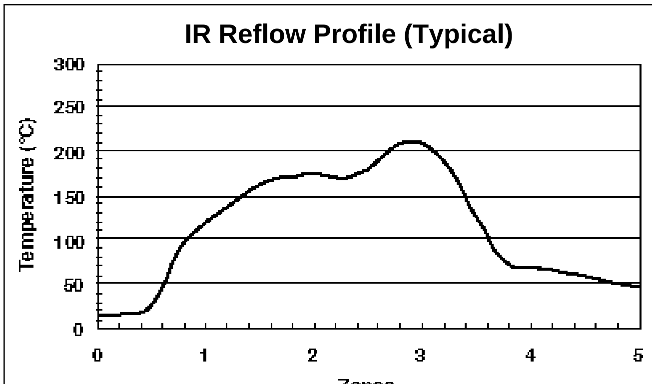

Figure 13

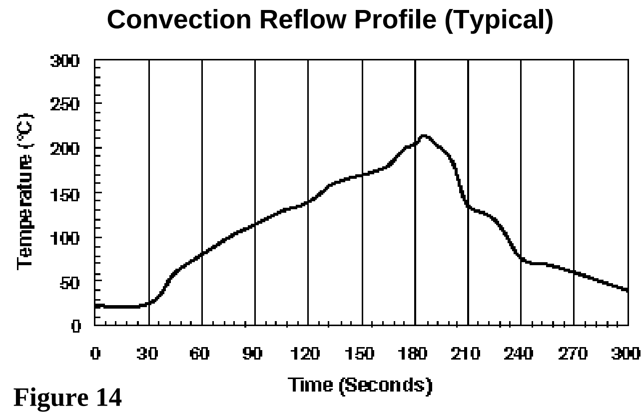

Figure 14

As can be seen by the above data tables, the parts easily withstood the rigors of surface mounting with little change in electrical parameters. These same types of tests were also performed on parts using convection as the reflow method (see Figure 14 for the profile) with comparable results.

Any part failure caused by overheating in reflow soldering will be evident as an immediate electrical reject, usually a low capacitance failure. Other than this process related phenomenon, no other long term aging characteristics are known that would effect usability.

The thermal withstanding capability of the MLP style chip capacitors has shown itself to be more than adequate for reflow solderable surface mount applications. As can be seen from the following graphs (Figures 17 and 18), reflow solder-

IR Reflow Test Results (1812 PET)

Type Test	IR Reflow
Part Number	104K100ST1812
Part Description	0.10µfd, 100 RVDC, ST, 1812

	Pre Test		Post Test		
Unit No.	Cap (µfds)	DF (E-4)	Cap (µfds)	DF (E-4)	Cap (%)
1	0.09937	38	0.09950	36	0.131
2	0.09803	37	0.09820	38	0.173
3	0.09513	36	0.09530	38	0.179
4	0.09543	42	0.09560	48	0.178
5	0.09346	48	0.09340	40	-0.064
6	0.09837	44	0.09840	39	0.030
7	0.09821	37	0.09840	38	0.193
8	0.09550	42	0.09560	42	0.105
9	0.10000	39	0.10011	39	0.110
10	0.09589	40	0.09600	39	0.144
Max.	0.10000	48	0.10011	48	0.193
Avg.	0.09694	40	0.09340	40	0.125

Figure 15

IR Reflow Test Results (2824 PET)					
Type Test	IR Reflow				
Part Number	105K100ST2824				
Part Description	1.00µfd, 100 RVDC, ST, 2824				
	Pre Test		Post Test		
Unit No.	Cap (µfds)	DF (E-4)	Cap (µfds)	DF (E-4)	Cap (%)
1	1.057	49	1.0566	57	-0.04
2	1.042	55	1.0415	59	-0.05
3	1.073	53	1.0720	58	-0.09
4	1.059	50	1.0586	55	-0.04
5	1.040	54	1.0362	59	-0.36
6	0.997	57	0.9941	61	-0.28
7	1.032	65	1.0256	64	-0.53
8	1.080	53	1.0790	58	-0.09
9	1.035	52	1.0346	58	-0.04
10	1.041	53	1.0408	58	-0.02
11	1.074	56	1.0287	57	-0.32
12	1.008	58	1.0707	55	-0.31
Max.	1.080	65	1.0790	64	-0.53
Avg.	1.044	54	1.0417	59	-0.14

Figure 16

% Capacitance Change vs Temperature

ST2824 1.0µfd & ST3827 2.20µfd 100VDC (typical)

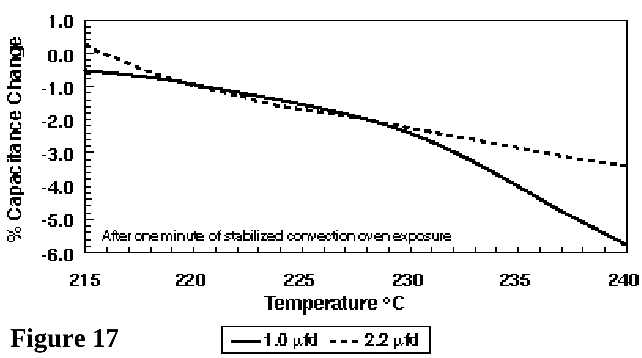

Figure 17

% Capacitance Change vs Time

ST2824 1.0µfd & ST3827 2.20µfd 100VDC (typical)

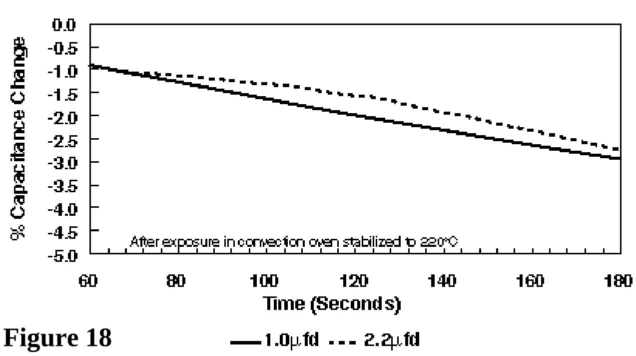

Figure 18

ing at 220°C for less than two minutes will have minimal effect on capacitance value.

PERFORMANCE AND RELIABILITY DATA

Unlike capacitors made with other dielectric systems, MLP capacitors are designed and tested for use at 100% of rated voltage at rated temperature. To accomplish this, they are subjected to established reliability testing of 125% of rated voltage at the maximum rated temperature. Statistically reducing the data back to actual use temperatures and voltages allows the users to determine the MTBF of their equipment. The inherent reliability of MLP capacitors is so high that it should be one of the least concerns that the equipment designer has in computing MTBF.

After being surface mounted on a number of test boards, the parts were subjected to accelerated dry life testing to ascertain their long term reliability. A summary of one such test is shown in Figure 19.

Capacitor Level Testing			
Type Test	Accelerated Dry Life		
Parameters	85°C/125VDC/4032Hrs		
Part Number	105K100ST2824		
Part Description	1.0µfd, 100 Rated VDC, ST		
Averages	Cap	%DF	IR
Pre	1.052	<.60	>2,000Meg
Post	1.043	<.40	>5,000Meg
% Change	-0.88		

Figure 19

Multiple sets of accelerated testing are done in order to accumulate significant numbers of component working hours. From these millions of component working hours it is then possible to statistically derive the potential percent failure rate of the capacitors under various conditions. The data table in Figure 20 shows just how low this potential rate currently is. Since the MLP style capacitor is relatively new, it does not yet have the 10's to 100's of millions of component hours test time that is normally associated with film capacitors. As further testing is completed to increase the total component test time, the % failure rate will continue to drop.

% Failure Rate per 1000 Hours @ 90% Confidence Level			
	@ %RVDC and 40°C		
Part Number	50%	75%	100%
105K100ST2824	0.0000	0.0003	0.0015

Figure 20

CONCLUSION

The MLP type capacitor provides equipment designers with an invaluable aid for easily improving their circuit designs. The compact chip capacitor made with polymer dielectric film provides for both high performance and unmatched reliability while its new packaging provides for ease of use in surface mounting.

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