ITW **Paktron**

Capacitor Guide for Mission Critical Applications

COTS: commercial off-the-shelf capacitors

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INDEX

INTRODUCTION

Company Background

With its headquarters in Lynchburg, Virginia, ITW Paktron is a multi-product, international company, consisting of manufacturing facilities in the United States and Taiwan.

ITW Paktron History:

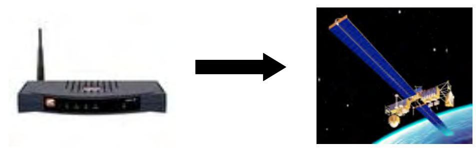
Time Frame	Event	
1953	ACF Electronics started in Alexandria, Virginia	
1960	Illinois Tool Works (ITW) purchases ACF's module division and renames it Paktron	
1966	Production start-up in Lynchburg, Virginia	
1969	Current Lynchburg facility built	
1982	Consolidated Production in Lynchburg	
1985	Production start-up of Angstor® Capacitors	MLP (multilayer polymer)
1992	Production start-up of Capstick® Capacitor	MLP (multilayer polymer)
1996	Production start-up of Surfilm® NG Capacitor	MLP (multilayer polymer)

Products:

- Angstor® Capacitors
- Capstick® Capacitors
- Quencharc® Snubber Networks
- Surfilm® Capacitors
- Capacitor manufacturing equipment and technology

Markets:

Commerical **Space**



One of the keys to ITW Paktron's continuing success has been in its "total technology" approach. Not only does Paktron manufacture the various components it sells, it also designs and manufactures all the equipment that it uses. This allows Paktron to not only produce high quality, mass manufactured (highly competitive) products, but also to sell its automatic production equipment, licenses, and know-how to many of the world's major industrial and developing nations. Having control over the technology in the production equipment allows for the production of the highest quality products possible, while expert knowledge of both the current and future requirements of the products allows for the construction of the "best" equipment possible.

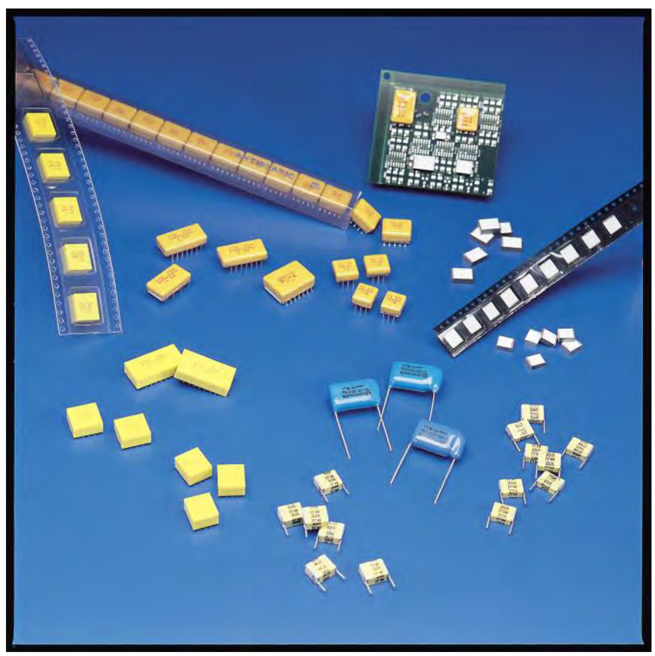


Figure 1 Paktron's Capacitors

Paktron is the technological leader in the manufacture of multilayer polymer film capacitors and sells across diverse markets including aeronautics, automotive, commercial, military, space and telecommunications. As a quality conscience company, Paktron follows the proven philosophy of building quality into its products. Inherent quality provides for both long-term reliability and outstanding product performance. Paktron's longevity is testament to its commitment to quality.

See Appendix A for a system summary on ITW Paktron. See Appendix B for a Paktron Product Catalog.

Product Background

Polymer film capacitors have been in commercial use since the 1950's. Although every year it seems that another futurist is predicting their demise by being supplanted by some radically new technology or having their market encroached upon by a competing capacitor technology, the polymer film capacitor market has instead experienced consistent growth in step with that of the economy itself. Due to their low mass, outstanding performance capabilities and unmatched inherent reliability, polymer film capacitors have long ago been established as the choice in high performance, mission critical applications. Instead of using capacitors that simply get by, critical applications require units with an established track record of both durability and reliability. Industries such as Telecom learned decades ago that while the other capacitor technologies have their viable uses, in pivotal applications only polymer film capacitors have the inherent performance, stability and reliability needed. The Telecom industry's commitment to using polymer film capacitors is such that companies like AT&T, GTE, Nortel and Siemens had once produced their own capacitors; until the commercial market was able to produce the quality and volumes levels that they required. Telecom is not alone, with other industries such as aerospace, the military and automotive having also produced their own polymer film capacitor products to meet their special needs.

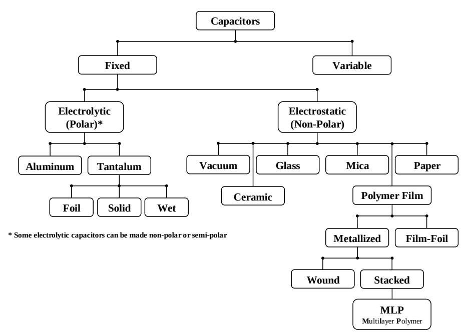


Figure 2 Family Tree of Capacitors

While polymer film capacitors have been around commercially for over 50 years they are not a stagnant technology but rather have evolved with the market needs to be smaller, more reliable and even higher performing. Polymer capacitors have gone from a simple wound film-foil construction to using metallized plates to stacked construction and finally to its latest iteration of MLP (multi layer polymer) construction (see Figure 2). Polymer capacitors are available in axial and radial lead configurations as well as special surface mountable constructions to meet various assembly needs. The polymer film market is not a cottage industry, producing job shop quantities of highly specialized capacitors, but rather is a high volume (totals in the billions of pieces per year worldwide) highly automated behemoth supplying products to every conceivable market. Polymer film capacitors can be found in markets ranging from the automotive industry to zero-current switching power converters. While the target applications have changed in each of these markets over the years (for instance, telecom went from having up to three polymer capacitors in every phone handset produced to it now being a rarity to find a polymer film capacitor in a handset, but the telco's central office and local branches are now consuming high quantities of polymer film capacitors in their various power conversion equipment).

MLP Construction

The latest innovation in film capacitor technology is Paktron's Interleaf® Technology used for the production of its MultiLayer Polymer (MLP) capacitors. This technology takes the concept of "stacked" film capacitors to its ultimate level in terms of size efficiency, ease of manufacture and overall performance. The Interleaf Process (see Figure 3) utilizes wide webbed rolls of material, completely aluminum metallized on one side. In the first production step, eight minute safety margins are laser ablated (demetallized) along the length of the film. The two margined rolls are then wound together on a large diameter wheel while being precisely slit into eight segments. This "winding" process creates eight separate stacks of well-aligned film that are called ropes. The ropes are cut to a consistent length, then loaded into fixtures and placed under high pressure. Pure aluminum is deposited on the rope edges that penetrates into the very small but precise film extensions to provide a highly conductive termination consisting of like metals. After a "reforming" process under high level thermal and pressure conditions (Patent #4741876), the dielectric film layers are not only laminated together, but also "reformed" at a molecular level so that their ability to handle any subsequent application of thermal stress has been greatly enhanced. At this point the ropes become perfectly flat, large capacitor "sticks" approximately 19 inches in length. For SMT devices that are directly mounted to the circuit board, a barrier layer is applied to the aluminum end termination and the barrier layer is coated with a lead (Pb) free solderable surface to facilitate board termination. These large stick capacitors are electrically tested and then severed into capacitor "blocks" that are the heart of the finished capacitor.

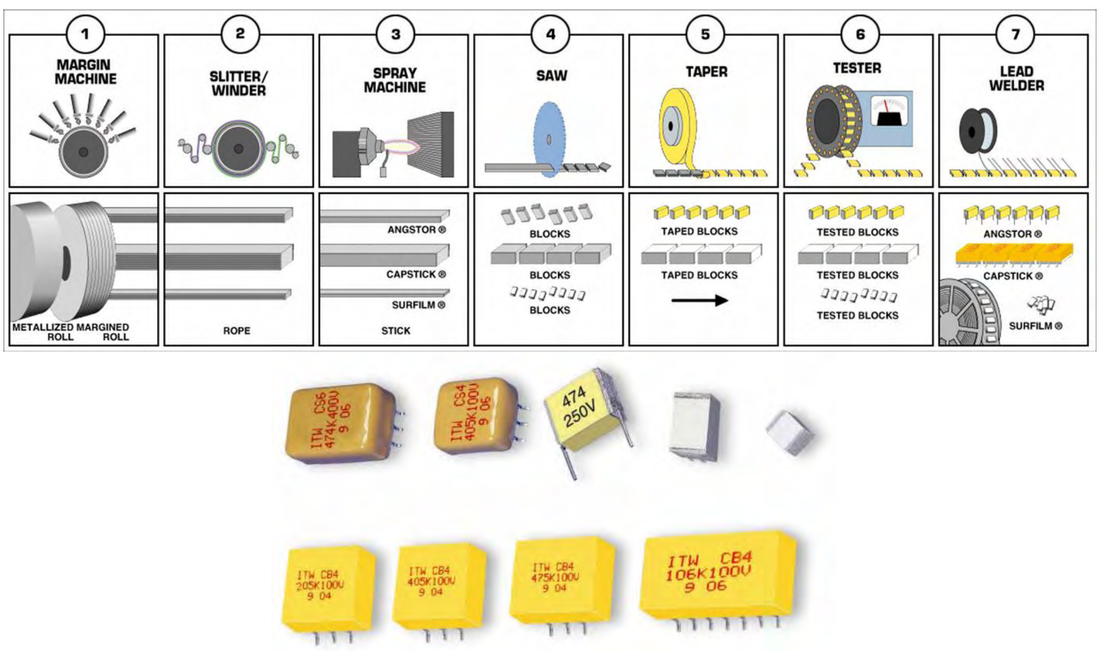


Figure 3 MLP Capacitor Flow & Examples

Polymer film capacitors are made with biaxially oriented files that can shrink in the X and Y directions while expanding in the Z direction (thickness) when subjected to heat above their original forming temperatures. Paktron took this into account while developing the Interleaf system to make film chip capacitors. In the process of making linear stacks of polymer film, the memory of the film is partially "erased" so the finished chip component has limited shrinkage and swelling during surface mount heat exposure. With this memory "erasing", chip capacitors are produced that can withstand reflow soldering methods with the currently specified limitation of 220 degrees Celsius. Combining both the advent of ultra thin polymer dielectric films of 1.4 micron thickness and below and the Interleaf® Technology (film chip capacitor) production system has allowed Paktron to meet the industry challenge of smaller size and surface mount compatibility. Figure 4 shows the cross section of the capacitor stack to illustrate the MLP construction. See appendix C for a listing of MLP advantages. See Appendix D for the various MLP "Product Process Flow and Control Plans".

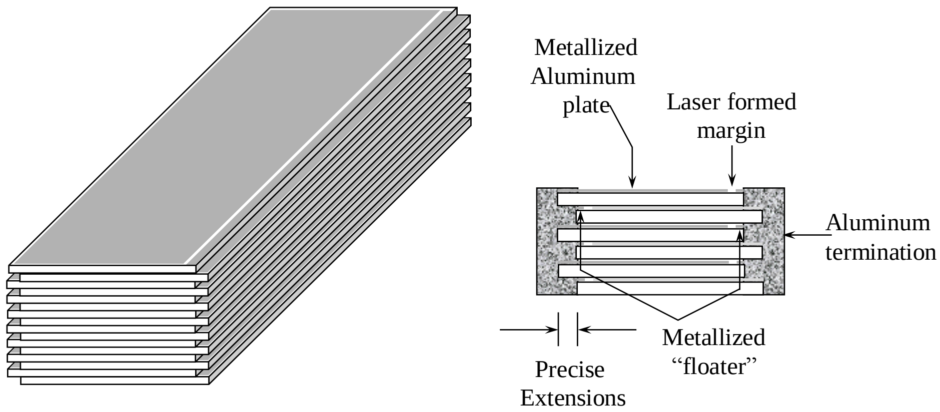


Figure 4 MLP Internal Structure

RoHS

RoHS (Restrictions On Hazardous Substances): restrictions on the use of certain hazardous substances in electrical and electronic equipment i.e. to ban certain hazardous materials such as lead.

Although the RoHS directive from the EU Commission actually specifies six distinct materials which may no longer be used in electrical and electronic devices the primary concern for the polymer film capacitor industry has been on the elimination of lead in electronic solder. This is because the other five materials have historically not been used in film capacitors while lead in the form of tin/lead solder has been used as a termination material.

Lead (Pb) exposure is being portrayed as a major health crisis that is gaining recognition around the world. Magazines, newspapers, television, and radio have been spreading the word about its risks, causing trade associations and governmental bodies to initiate proceedings to investigate the elimination of lead from electrical and electronic solder with emphasis being placed on the amount of consumer waste containing lead that is being deposited in landfills possibly contaminating both surrounding land and water supplies. While a great deal of work has been done in the Asian (Japan) and US markets to facilitate the removal of lead from solder on a voluntary basis, the regulatory lead has been taken by Europe with the EU Commission's Directive on banning the use of lead in solder in electrical and electronic equipment. Both the Asian and US markets are following Europe's lead rather than face any possible trade restrictions on the import of their products into the European market. The drive to reduce the use of lead is not new. Lead in domestic water pipes, plumbing solders, gasoline, paint, fishing weights and ammunition etc, has long been the center of both environmental and "green" pressures. While these are important areas of possible contamination, it should be noted that the scientific basis for considering lead in electronic components as a contributing factor in the danger to the environment and to human life is questionable at best. In over 25 years of meticulous testing by both private and public groups, there has not been one documented case of lead from electronic solder "escaping" from a public landfill. Solely by name association with other "active" forms of lead, leaded solder is being defined as evil and has been targeted for banning.

One of the most confusing aspects of the RoHS directives is the lack of definition of what classifies critical technology. The stated intent of the RoHS directives is to reduce the amount of harmful waste going into landfills by reducing the hazardous material content of "innovative class" type commodity products (i.e. cell phones, portable audio players, televisions etc.). "Innovative class" products have relatively short lifetimes and a failure in one is rarely life threatening. The conversion of durable, mission critical products (pacemakers, aircraft, automotive, satellites, military, etc.) was intended to be delayed for at least four (4) years after the "innovative class" conversion to allow for advances in technology and documentation of any potential drawbacks in converting mission critical applications to lead-free processing. Unfortunately, because so many Original Equipment Manufacturers (OEMs) have turned their manufacturing over to Contract Manufacturers (CMs) the processing distinction between "innovative class" commodity products and durable, mission critical class products has now overlapped. The CMs cannot afford to run and supply two separate production lines; one for leaded product and one for lead-free product and they as well as some OEMs are attempting to take all their manufacturing to lead-free processing on the July 2006 deadline schedule. This produces an at-risk condition for mission critical industries such as Servers, Storage, Network and Telecom equipment, Medical, Aerospace, Military, Avionics and Automotive where a system failure is either singularly life threatening or catastrophic in nature.

In response to RoHS Paktron has taken the position of maintaining its standard, volume oriented product with tin/lead solder on the lead terminations. This has been done because polymer film capacitors are generally used in high reliability, mission critical applications. With over 50 years of industry testing as proof, for safety, performance and reliability reasons, terminations (secondary interconnect: i.e. terminal leads and lead frames) used in these applications require the use of tin/lead (Sn/Pb) coatings. Paktron uses the unofficial, but widely used and accepted terminology of calling product which does not contain any of the six RoHS restricted materials as RoHS-6 compliant while products containing lead in the lead termination coatings only are classified as RoHS-5 compliant. Paktron's RoHS-5 product maintains a lead content under 1000ppm relative to total component weight, but does not meet the 1000ppm RoHS lead content limit in terms of homogeneous material (in this case the lead termination coating). The bulk of Paktron's standard product offerings is RoHS-5 while RoHS-6 compliant product with lead-free terminations (matte or fused tin) are available but only on special order with limited availability and subject to minimum order quantities. See Appendix E for Paktron's RoHS position paper.

Applications

While polymer film capacitors are used in high volume in commercial, innovative class applications their usage in mission critical applications continues to prove that they are in a performance class by themselves. While almost all capacitors are durable/reliable within the scope of their specifications, there are specific applications that require an enhanced durability/reliability wherein the inherent performance of the capacitor goes far beyond that necessary to just get by. Over twenty years ago, Telecom (the telecommunications industry) had the most stringent component specifications of any industry. With its mandated minimum of twenty years of life and equipment requirements of no more than 15 seconds of downtime per year, only the “best of the best” components could be used. With deregulation and the necessity to reduce costs, the equipment life cycle was reduced to 10 years and in some cases all the way down to 1 year. This however was not done across the board. In its critical applications Telecom has continued requiring the use of capacitors with established track records in both durability and reliability. For these applications, only capacitors with the necessary inherent performance, stability and reliability are used and in most cases these are polymer film capacitors. Telecom is not the only industry requiring enhanced durability/reliability. The Internet has been transformed from being a purely educational/governmental messaging service to a highly commercialized information interchange and B2B economic tool. Along with that transformation, Datacom’s critical equipment requirements for durability and reliability have increased dramatically. With the Datacom industry seeking to achieve the same 5x9 (99.999%) up-time reliability levels required in critical Telecom applications, the choice of the proper components used in such critical Datacom applications as high-density power converters has become more crucial than ever. The new demands on the Datacom industry to match the 10 to 20 year life of the Telecom industry’s almost 100% up-time products are drastically changing their component selection criteria. These of course are not the only industries that require enhanced durability and reliability. Almost every industry has a set of critical applications wherein only the “best of the best” components can be used. Planned obsolescence may be acceptable for low-cost throw-away commodity items such as blow dryers and telephone handsets, but consumers demand certain levels of satisfaction (durability/reliability) in many of the products they buy/use.

In terms of aeronautics, military and space applications, polymer film capacitors have been used as in these markets critical circuits since the capacitors were first introduced over 50 years ago. As commercially priced and distributor available products, Paktron’s MLP capacitors are used in anything from ground based communications equipment to low orbit satellites to the space shuttle and even on deep space missions.

Figure 5

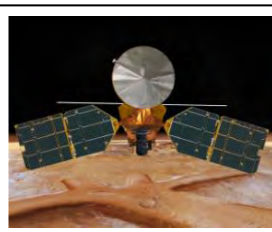


Figure 6

Figure 7

Figure 8

This custom applications guide covers the three main areas of applications for ITW Paktron capacitors. Other applications in Lighting and Automotive also exist, but the applications discussed here cover the majority of the market.

ITW Paktron manufactures plastic film capacitors using a specialized technology that produces parts with some special properties. We refer to the parts as MLP (Multilayer Polymer) in the same way as MLC refers to Multilayer Ceramic. The Paktron MLP Capacitors are high value relative to their small size. The parts are constructed to operate at very high frequency and can handle very large ripple current. Compared to MLC capacitors, the MLP styles are much more stable and offer important electrical improvement over MLC's. The MLP types are SMT compatible and this is rare in film capacitors.

The MLP Capacitor is mainly used in high current and mid to high voltage applications (usually above 24 volts) where MLC capacitors are not stable and prone to short circuit failure. Typical applications are Input Filters in Telecom, Bypass Capacitors in Off-Line Power, and EMI (differential noise) Filters on AC and DC input lines.

Please read Appendix G (Paktron Technical Bulletin 3.01) for supplemental detailed information.

DC Input Filtering and Bypass

Target markets: Telecom, Datacom, Modems and DC-to-DC Converters.
Applications: Power Converters, Power Inverters, Telecom Card Edge Filters, Data Modems, Blade Servers, and Optical Networks.
Capacitors Used: 4.0 to 10.0 µF Capstick Capacitors; the larger valued Angstor RA types with values up to 4.0 microfarads are also sometimes used.

Application:
The input voltage can range from 24 to 72 volts, but the nominal input voltages are 24 and 48 volts. The input capacitors are 100 volts for the popular –48volt input.

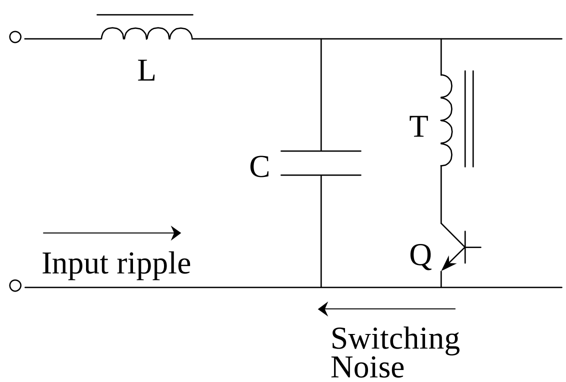


Figure 11 Bypass Filter

The "input capacitor" is needed to bypass any AC (ripple voltage) portion of the input voltage while allowing the DC voltage to appear on both sides of the circuit. The level of the input ripple voltage and switching frequency of the circuit determines the cap value. The MOS-FET switch creates noise at its switching frequency and harmonics of this primary frequency. A 200-kilohertz switch can emit noise (reflected RFI) at 20 to 30 megahertz back to the input and into the utility line. The input capacitor can attenuate this radio frequency noise, effectively grounding this unwanted EMI from polluting the input line. The key to this application is a capacitor that operates over a very wide frequency range and can handle large ripple current without shorting or heating up.

AC Input Filtering

Target markets:	AC to DC Power Supplies and General Line Filtering.
Applications:	High frequency (over 100 kilohertz) power converters, harmonic attenuation modules and power factor correction circuits.
Capacitors Used:	The Angstor RA and Capstick CS series of MLP Capacitors. They are available at various input voltages including 250, 400 and 500 volts to cover the whole range of universal input voltages.

Application:
The input voltage may be high voltage AC or boosted DC to 400 or 500 volts.

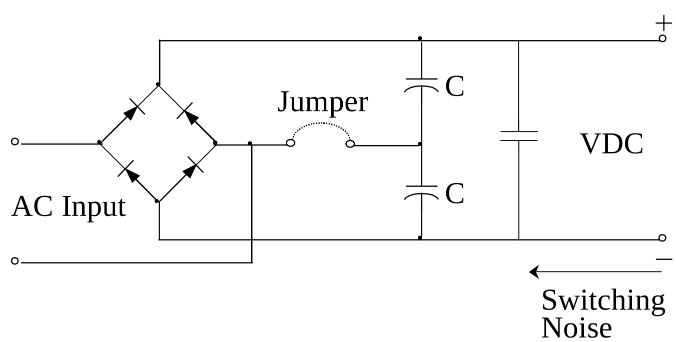


Figure 12 AC and Quasi AC Input Filter

The input ripple voltage is very large so normally large value electrolytic capacitors are use on the input. A high frequency capacitor is also needed for noise control (reflected RFI) in parallel to the aluminum electrolytic. This is a strong application for a low ESR (low resistance) film capacitor because ceramic capacitors are not stable and lose cap value under the high stress of the input voltage. Other film capacitors may be used, but the MLP type has better high frequency response to bypass the radio frequency noise.

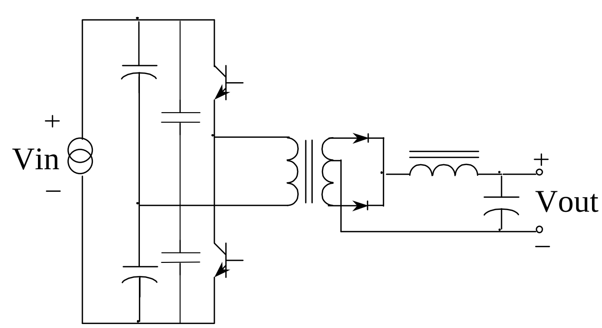


Figure 13 High Voltage Input Filter

ARC Suppression and Snubber Networks

Target customers are mainly Industrial applications where the following are required:
- Relay contact protection
- Noise reduction on PLC controllers/drivers
- dv/dt suppression on thyristor and triacs
- EMI/RFI reduction
- Reduction of inductive noise from "solenoid valves"

ITW Paktron's **Quencharc® Capacitor**, **Type Q/QRL** is the most widely recognized trademark in the industry for a RC (resistor-capacitor) Network. An RC network is the most popular and commonly used method for relay contact arc suppression and PLC noise reduction, caused by inductive loads turning on-off. The RC is typically installed across the control relay contacts (see Fig. A) or in parallel to the inductive load (see Fig. B).

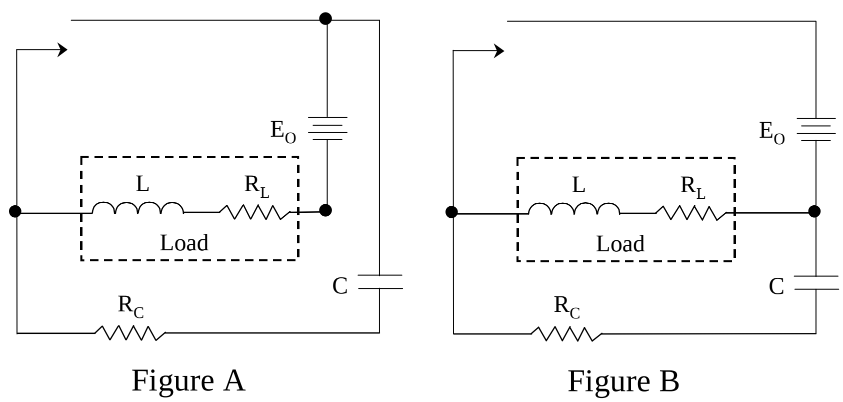


Figure 14

General equations for the selection of resistance and capacitance are:

$$C = \frac{I^2}{10} \qquad R = \frac{E_O}{10I(1+\frac{50}{E_O})}$$

Where:

C = capacitance in µF
I = load current in amps
R = resistance in ohms in series with capacitor
E_O = source voltage

These equations are only guidelines and the final selection must be evaluated in the application to determine its acceptability. In many cases, a 0.1 µF 600VDC/250VAC capacitor and a 100 ohm ½ watt resistor (P/N: 104M06QC100) is a common solution or a starting point from which to work.

Capacitor Test Data

Capstick Test Packet Contents

1. Life Testing
    a. Accelerated DC Dry Life Test (85°C / 125vdc / 2000 hrs): 106K100CS4
    b. Accelerated DC Dry Life Test (85°C / 500vdc / 2000 hrs): 474K400CS6
    c. Accelerated DC Dry Life Test (125°C / 62.5vdc / 2000 hrs): 106K100CB4
2. Moisture Resistance Testing
    a. Accelerated Moisture Test (85%RH/85°C / / 2000 hrs): 405K100CB4
    b. Accelerated Moisture Test (85%RH/85°C / 100vdc / 2000 hrs): 405K100CS4
3. Vibration Testing
    a. SMT Vibration Test (MIL-STD-202E, Method 204D): 106K100CB4G
    b. SMT Vibration Test (MIL-STD-202E, Method 204D): 405K100CS4G

ITW Paktron

Test File Comparison Report
106K100CS4

12/8/01

Test File Data

Tests	Code Names	Operators	Test Type
Initial	010909P011Ca	K.C.	Performance evaluation
Final	010909P011Ce	K.C.	Dry life

Test Criteria

Voltage	Temperature	%RH	Duration
125VDC	85°C ± 3°C	NA	2000 hrs ± 12 hrs

Special: Standard CS4 units.
Tested to IEC 384-1, paragraph 4.23

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	10.023	0.23	0.55	2,000	9.998	-0.02	-0.25	0.46	20,000
2	10.227	2.27	0.56	3,000	10.198	1.98	-0.28	0.47	15,000
3	9.844	-1.56	0.57	6,000	9.834	-1.66	-0.10	0.50	12,000
4	9.829	-1.71	0.57	1,200	9.825	-1.75	-0.04	0.55	17,000
5	10.102	1.02	0.57	2,500	10.096	0.96	-0.06	0.47	28,000
6	9.947	-0.53	0.57	2,400	9.912	-0.88	-0.35	0.48	28,000
7	9.941	-0.59	0.63	9,000	9.941	-0.59	0.00	0.49	33,000
8	9.603	-3.97	0.56	1,500	9.601	-3.99	-0.02	0.47	20,000
9	9.898	-1.02	0.57	1,600	9.892	-1.08	-0.06	0.48	12,000
10	10.001	0.01	0.63	7,000	10.008	0.08	0.07	0.48	10,000
11	9.893	-1.07	0.59	6,000	9.889	-1.11	-0.04	0.46	14,000
12	9.658	-3.42	0.56	5,000	9.657	-3.43	-0.01	0.49	15,000
13	9.854	-1.46	0.58	1,500	9.851	-1.49	-0.03	0.55	23,000
14	9.856	-1.44	0.55	7,000	9.851	-1.49	-0.05	0.51	25,000
15	9.637	-3.63	0.58	8,000	9.587	-4.13	-0.52	0.53	13,000
16	9.928	-0.72	0.59	7,000	9.915	-0.85	-0.13	0.54	30,000
17	9.956	-0.44	0.53	4,500	9.956	-0.44	0.00	0.51	22,000
18	9.549	-4.51	0.58	7,000	9.548	-4.52	-0.01	0.51	18,000
19	9.861	-1.39	0.58	4,500	9.859	-1.41	-0.02	0.49	15,000
20	10.012	0.12	0.59	4,000	9.995	-0.05	-0.17	0.50	17,000
21	9.950	-0.50	0.57	2,200	9.963	-0.37	0.13	0.53	21,000
22	9.580	-4.20	0.57	2,600	9.604	-3.96	0.25	0.52	27,000
23	9.915	-0.85	0.57	5,000	9.920	-0.80	0.05	0.47	18,000
24	9.720	-2.80	0.59	1,000	9.724	-2.76	0.04	0.47	32,000
25	9.810	-1.90	0.56	9,000	9.814	-1.86	0.04	0.46	24,000
Max	10.227	2.27	0.63	9,000	10.198	1.98	0.25	0.55	33,000
Min	9.549	-4.51	0.53	1,000	9.548	-4.52	-0.52	0.46	10,000
Avg	9.864	-1.36	0.57	4,420	9.858	-1.42	-0.06	0.50	20,360
Std	0.165	1.65	0.02	2,384	0.162	1.62	0.16	0.03	6,498
Range	0.678	6.78	0.10	8,000	0.6500	6.50	0.77	0.09	23,000

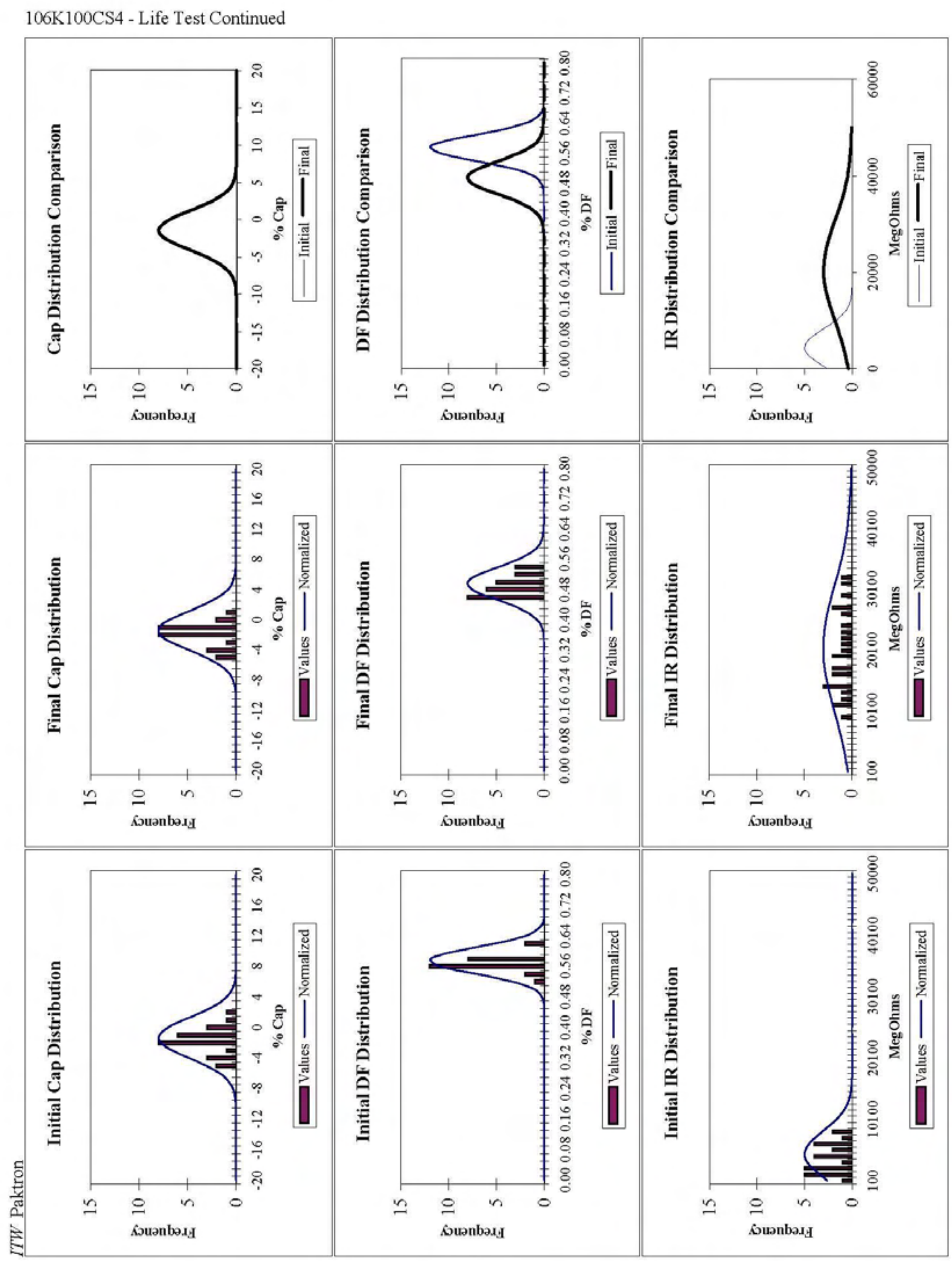
Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	5.00	0.52	√
%DF (max)	1.00	0.55	√
IR (min)	100.0	10,000	√

Notes:

Test parts successfully meet performance criteria.


106K100CS4 - Life Test Continued
ITW Paktron
Initial Cap Distribution
Final Cap Distribution
Cap Distribution Comparison
Initial DF Distribution
Final DF Distribution
DF Distribution Comparison
Initial IR Distribution
Final IR Distribution
IR Distribution Comparison
Frequency
% Cap
% DF
MegOhms
Values
Normalized
Initial
Final

ITW Paktron

Test File Comparison Report
474K400CS6

3/16/01

Test File Data

Tests	Code Names	Operators	Test Type
Initial	001222R08Aa	B.A.	Performance evaluation
Final	001222R08Da	B.A.	Dry life

Test Criteria

Voltage	Temperature	%RH	Duration
500VDC	85°C ± 3°C	NA	2000 hrs ± 12 hrs

Special: Standard CS6 units.
Tested to IEC 384-1, paragraph 4.23

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	0.4710	0.21	0.43	11,500	0.4690	-0.21	-0.42	0.44	50,000
2	0.4530	-3.62	0.50	9,500	0.4420	-5.96	-2.43	0.45	45,000
3	0.4700	0.00	0.56	13,500	0.4690	-0.21	-0.21	0.45	60,000
4	0.4740	0.85	0.54	9,500	0.4730	0.64	-0.21	0.45	35,000
5	0.4690	-0.21	0.51	8,500	0.4670	-0.64	-0.43	0.45	40,000
6	0.4620	-1.70	0.54	10,500	0.4600	-2.13	-0.43	0.45	45,000
7	0.4670	-0.64	0.53	15,500	0.4650	-1.06	-0.43	0.47	60,000
8	0.4720	0.43	0.49	8,500	0.4710	0.21	-0.21	0.47	50,000
9	0.4690	-0.21	0.57	24,500	0.4680	-0.43	-0.21	0.44	60,000
10	0.4480	-4.68	0.69	12,500	0.4470	-4.89	-0.22	0.48	55,000
11	0.4650	-1.06	0.61	18,500	0.4630	-1.49	-0.43	0.49	40,000
12	0.4510	-4.04	0.50	10,500	0.4500	-4.26	-0.22	0.45	40,000
13	0.4640	-1.28	0.49	13,500	0.4610	-1.91	-0.65	0.46	50,000
14	0.4720	0.43	0.52	9,500	0.4710	0.21	-0.21	0.45	35,000
15	0.4670	-0.64	0.51	16,500	0.4660	-0.85	-0.21	0.45	40,000
16	0.4690	-0.21	0.52	12,500	0.4680	-0.43	-0.21	0.45	25,000
17	0.4540	-3.40	0.51	10,500	0.4530	-3.62	-0.22	0.46	40,000
18	0.4670	-0.64	0.62	18,500	0.4660	-0.85	-0.21	0.45	27,000
19	0.4770	1.49	0.54	9,500	0.4750	1.06	-0.42	0.47	45,000
20	0.4490	-4.47	0.51	10,500	0.4480	-4.68	-0.22	0.43	55,000
21	0.4730	0.64	0.50	9,500	0.4720	0.43	-0.21	0.41	45,000
22	0.4740	0.85	0.48	12,500	0.4730	0.64	-0.21	0.41	60,000
23									
24									
25									
Max	0.4770	1.49	0.69	24,500	0.4750	1.06	-0.21	0.49	60,000
Min	0.4480	-4.68	0.43	8,500	0.4420	-5.96	-2.43	0.41	25,000
Avg	0.4653	-1.00	0.53	12,545	0.4635	-1.38	-0.39	0.45	45,545
Std	0.0085	1.82	0.05	3,914	0.0093	1.98	0.46	0.02	10,040
Range	0.0290	6.17	0.26	16,000	0.0330	7.02	2.22	0.08	35,000

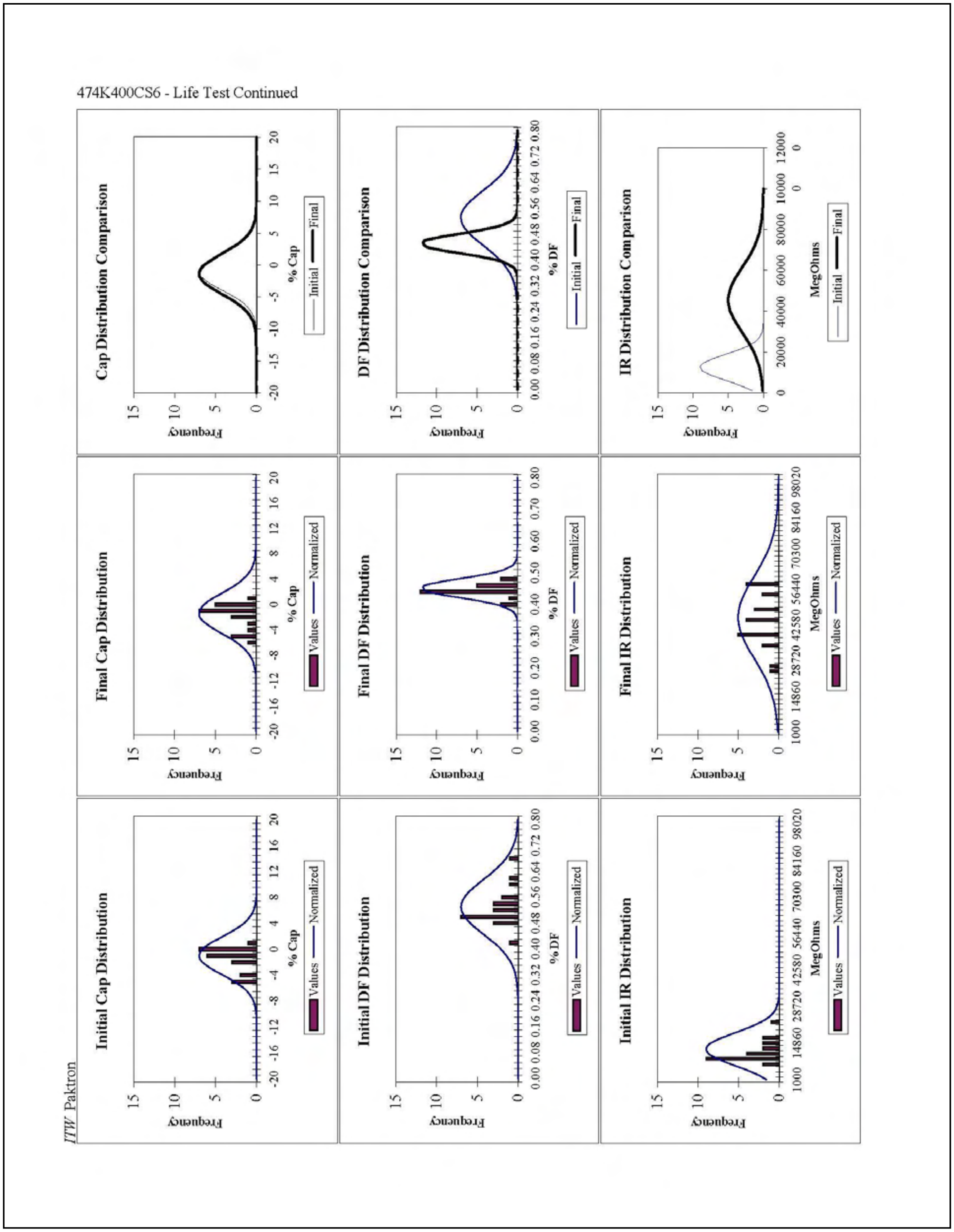
Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	5.00	2.43	√
%DF (max)	1.00	0.49	√
IR (min)	1,000	25,000	√

Notes:

Test parts successfully meet performance criteria.


474K400CS6 - Life Test Continued
ITW Paktron
Initial Cap Distribution
Final Cap Distribution
Cap Distribution Comparison
Initial DF Distribution
Final DF Distribution
DF Distribution Comparison
Initial IR Distribution
Final IR Distribution
IR Distribution Comparison
Frequency
% Cap
% DF
MegOhms
Values
Normalized
Initial
Final

ITW Paktron

Test File Comparison Report
106K100CB4

5/16/2003

Test File Data

Tests	Code Names	Operators	Test Type
Initial	008073R08Aa	K.C.	Performance evaluation
Final	008073R08Da	K.C.	Dry life

Test Criteria

Voltage	Temperature	%RH	Duration
62.5VDC	125°C ± 3°C	NA	2000 hrs ± 12 hrs

Special: Standard CB4 units.
Tested to IEC 384-1, paragraph 4.23

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	9.2050	-7.95	0.50	5,000	8.9049	-10.95	-3.26	0.44	7,389
2	9.0700	-9.30	0.51	6,000	8.7937	-12.06	-3.05	0.44	7,705
3	9.5300	-4.70	0.52	4,500	9.4990	-5.01	-0.33	0.45	7,841
4	9.2690	-7.31	0.51	4,500	9.2090	-7.91	-0.65	0.44	5,913
5	9.3120	-6.88	0.53	3,200	9.0251	-9.75	-3.08	0.45	7,470
6	9.9250	-0.75	0.50	1,300	9.7543	-2.46	-1.72	0.43	5,650
7	9.2640	-7.36	0.52	2,500	9.0515	-9.49	-2.29	0.45	6,441
8	9.2960	-7.04	0.53	2,000	9.0832	-9.17	-2.29	0.45	5,249
9	9.1080	-8.92	0.51	8,000	8.9293	-10.71	-1.96	0.43	9,713
10	9.3960	-6.04	0.52	9,000	9.1855	-8.14	-2.24	0.44	10,405
11	9.0170	-9.83	0.52	3,800	8.8362	-11.64	-2.01	0.45	5,568
12	9.1400	-8.60	0.52	6,000	8.9260	-10.74	-2.34	0.45	7,943
13	9.2070	-7.93	0.49	7,000	8.9723	-10.28	-2.55	0.43	8,778
14	9.0240	-9.76	0.50	4,000	8.9856	-10.14	-0.43	0.43	7,906
15	9.9280	-0.72	0.53	8,000	9.9204	-0.80	-0.08	0.46	9,539
16	9.2600	-7.40	0.53	5,500	9.2125	-7.88	-0.51	0.45	8,661
17	9.3130	-6.87	0.53	5,000	9.3179	-6.82	0.05	0.46	7,326
18	9.9140	-0.86	0.52	6,000	9.6479	-3.52	-2.68	0.44	8,520
19	9.2600	-7.40	0.53	6,000	8.9149	-10.85	-3.73	0.45	8,741
20	9.2870	-7.13	0.50	5,500	9.2059	-7.94	-0.87	0.43	8,092
21	9.0890	-9.11	0.53	8,500	9.0613	-9.39	-0.30	0.46	10,174
22	9.3760	-6.24	0.51	3,000	9.0366	-9.63	-3.62	0.44	7,322
23	9.9970	-0.03	0.53	6,000	9.7724	-2.28	-2.25	0.46	8,981
24	9.1320	-8.68	0.53	1,900	8.9159	-10.84	-2.37	0.45	4,761
25	9.0240	-9.76	0.53	7,000	8.8557	-11.44	-1.87	0.46	8,829
Max	9.9970	-0.03	0.53	9,000	9.9204	-0.80	0.05	0.46	10,405
Min	9.0170	-9.83	0.49	1,300	8.7937	-12.06	-3.73	0.43	4,761
Avg	9.3337	-6.66	0.52	5,168	9.1607	-8.39	-1.86	0.44	7,797
Std	0.2909	2.91	0.01	2,084	0.3127	3.13	1.15	0.01	1,500
Range	0.9800	9.80	0.04	7,700	1.1266	11.27	3.78	0.03	5,644

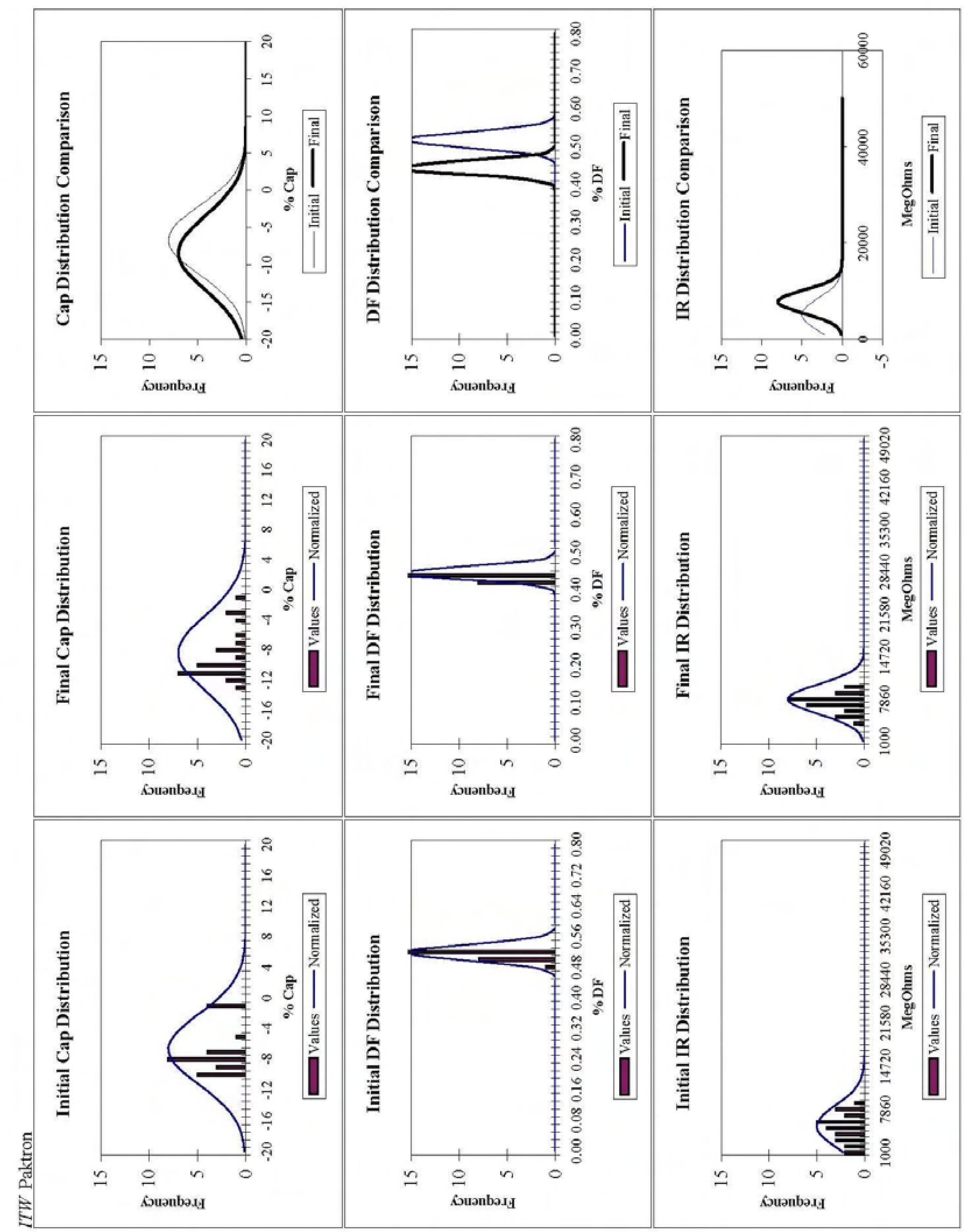
Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	5.00	3.73	√
%DF (max)	1.00	0.46	√
IR (min)	1,000	4,761	√

Notes:

Test parts successfully meet performance criteria.


ITW Paktron
Initial Cap Distribution
Final Cap Distribution
Cap Distribution Comparison
Initial DF Distribution
Final DF Distribution
DF Distribution Comparison
Initial IR Distribution
Final IR Distribution
IR Distribution Comparison
Frequency
% Cap
% DF
MegOhms
Values
Normalized
Initial
Final

ITW Paktron

Test File Comparison Report
405K100CB4

5/21/01

Test File Data

Tests	Code Names	Operators	Test Type
Initial	010521P002Ca	K.C.	Performance evaluation
Final	010521P002Ce	K.C.	Moisture Resistance

Test Criteria

Voltage	Temperature	%RH	Duration
	85°C ± 3°C	85%	2000 hrs ± 12 hrs

Special: Standard CB4 units.
Tested to IEC 68-2-3 (steady state moisture resistance test, no applied voltage),
except: 85°C instead of 40°C, 85%RH instead of 95% and 83.3days instead of 56.

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	4.052	1.30	0.68	3,000	4.190	4.75	3.41	0.46	1,700
2	4.099	2.48	0.65	1,100	4.229	5.73	3.17	0.45	6,500
3	4.135	3.38	0.48	6,000	4.282	7.05	3.56	0.46	4,000
4	4.095	2.38	0.66	2,000	4.236	5.90	3.44	0.45	7,000
5	4.083	2.08	0.70	4,500	4.220	5.50	3.36	0.45	6,000
6	4.060	1.50	0.67	2,200	4.187	4.68	3.13	0.45	6,500
7	4.120	3.00	0.48	8,000	4.274	6.85	3.74	0.46	5,000
8	4.083	2.08	0.52	1,500	4.230	5.75	3.60	0.45	5,500
9	4.054	1.35	0.57	1,200	4.186	4.65	3.26	0.45	6,000
10	4.248	6.20	0.55	7,000	4.386	9.65	3.25	0.46	7,000
11	4.127	3.18	0.58	6,000	4.259	6.48	3.20	0.47	6,000
12	4.190	4.75	0.60	4,500	4.339	8.48	3.56	0.48	4,000
13	4.150	3.75	0.58	6,000	4.284	7.10	3.23	0.45	4,000
14	4.048	1.20	0.56	1,100	4.182	4.55	3.31	0.46	5,500
15	4.190	4.75	0.59	1,200	4.314	7.85	2.96	0.45	1,600
16	4.081	2.03	0.54	1,100	4.210	5.25	3.16	0.47	2,000
17	4.062	1.55	0.50	1,100	4.197	4.93	3.32	0.46	6,500
18	4.050	1.25	0.47	4,500	4.174	4.35	3.06	0.45	4,500
19	4.088	2.20	0.51	1,500	4.224	5.60	3.33	0.46	5,000
20	3.944	-1.40	0.51	6,500	4.071	1.78	3.22	0.56	6,000
21	4.063	1.58	0.48	1,200	4.204	5.10	3.47	0.47	2,200
22	3.938	-1.55	0.55	8,000	4.061	1.53	3.12	0.51	2,400
23									
24									
25									
Max	4.248	6.20	0.70	8,000	4.386	9.65	3.74	0.56	7,000
Min	3.938	-1.55	0.47	1,100	4.061	1.53	2.96	0.45	1,600
Avg	4.089	2.23	0.57	3,600	4.225	5.61	3.31	0.47	4,768
Std	0.069	1.74	0.07	2,471	0.073	1.83	0.19	0.02	1,750
Range	0.310	7.75	0.23	6,900	0.3250	8.13	0.78	0.11	5,400

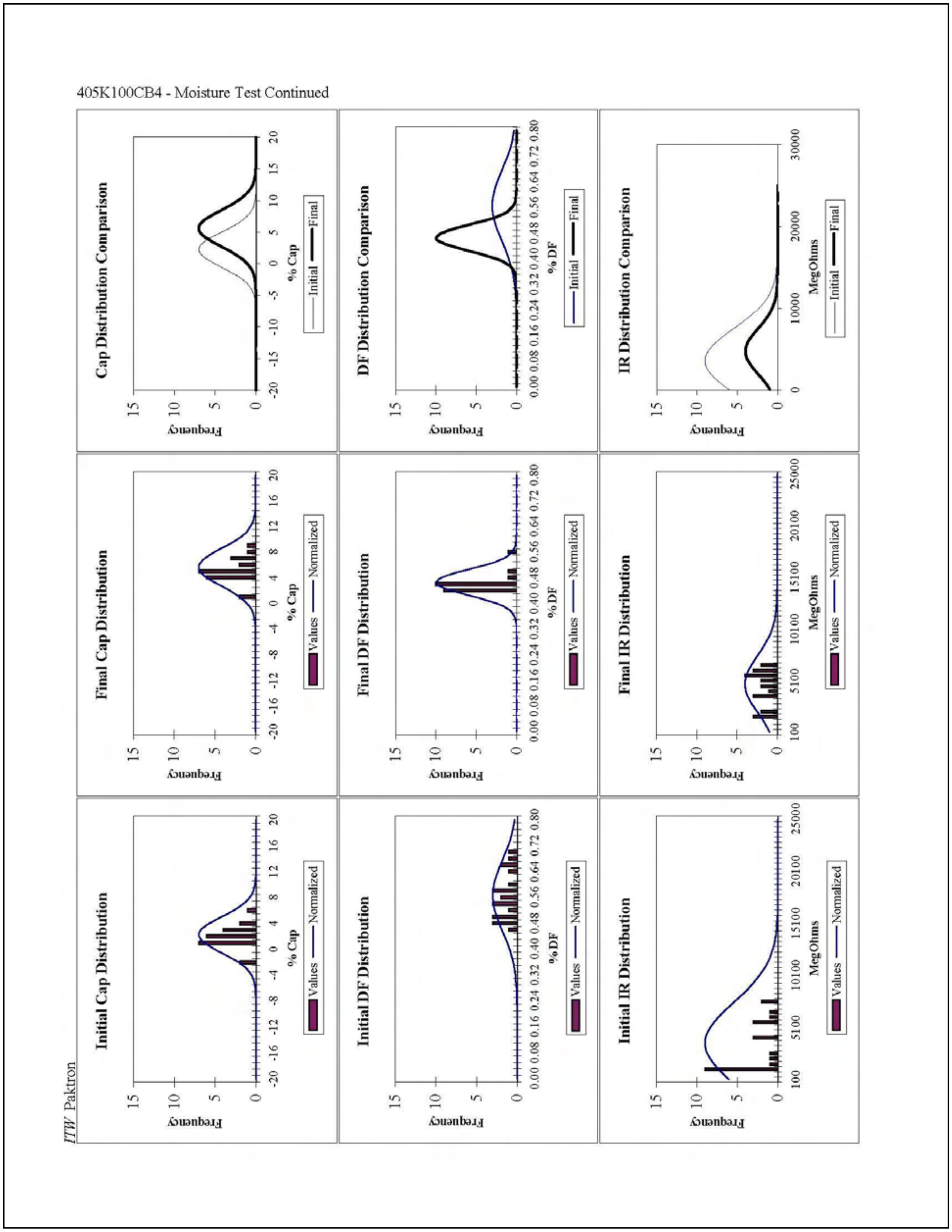
Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	7.00	3.74	√
%DF (max)	1.00	0.56	√
IR (min)	82.5	1,600	√

Notes:

Test parts successfully meet performance criteria.


405K100CB4 - Moisture Test Continued
ITW Paktron
Initial Cap Distribution
Final Cap Distribution
Cap Distribution Comparison
Initial DF Distribution
Final DF Distribution
DF Distribution Comparison
Initial IR Distribution
Final IR Distribution
IR Distribution Comparison
Frequency
% Cap
% DF
MegOhms
Values
Normalized
Initial
Final

ITW Paktron

Test File Comparison Report
405K100CS4

12/20/01

Test File Data

Tests	Code Names	Operators	Test Type
Initial	010924P002Ca	K.C.	Performance evaluation
Final	010924P002Ce	K.C.	Moisture Resistance

Test Criteria

Voltage	Temperature	%RH	Duration
100VDC	85°C ± 3°C	85%	2000 hrs ± 12 hrs

Special: Standard CS4 units.
Tested to IEC 68-2-3 (steady state moisture resistance test, applied voltage),
except: 85°C instead of 40°C, 85%RH instead of 95% and 83.3days instead of 56.

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	4.172	4.31	0.57	5,000	4.169	4.22	-0.09	0.48	18,000
2	4.005	0.13	0.55	9,000	4.032	0.80	0.66	0.56	24,000
3	3.994	-0.16	0.53	1,200	4.024	0.61	0.76	0.47	12,000
4	4.005	0.13	0.51	2,500	4.039	0.99	0.85	0.51	10,625
5	4.074	1.84	0.51	7,000	4.104	2.60	0.75	0.51	17,000
6	4.081	2.03	0.58	1,300	4.066	1.65	-0.37	0.51	6,000
7	4.112	2.79	0.50	4,500	4.142	3.55	0.74	0.49	12,000
8	4.100	2.51	0.51	6,000	4.123	3.07	0.56	0.50	11,143
9	4.009	0.22	0.51	1,500	4.036	0.89	0.66	0.49	5,000
10	4.039	0.99	0.52	5,000	4.066	1.65	0.66	0.50	6,400
11	4.089	2.22	0.53	6,000	4.119	2.98	0.74	0.50	10,000
12	4.112	2.79	0.57	4,200	4.142	3.55	0.74	0.53	7,000
13	4.142	3.55	0.57	5,000	4.172	4.31	0.73	0.54	9,000
14	4.081	2.03	0.54	2,400	4.115	2.88	0.84	0.52	14,000
15	4.134	3.36	0.51	2,000	4.165	4.12	0.74	0.52	10,667
16	4.138	3.46	0.51	4,000	4.169	4.22	0.73	0.51	9,000
17	4.093	2.32	0.51	4,000	4.123	3.07	0.74	0.50	10,000
18	4.039	0.99	0.52	8,000	4.058	1.46	0.47	0.51	12,000
19	3.994	-0.14	0.59	1,800	4.031	0.76	0.90	0.51	18,000
20	3.971	-0.72	0.51	6,000	4.001	0.03	0.77	0.49	20,000
21	4.123	3.07	0.54	1,400	3.963	-0.91	-3.87	0.52	15,000
22	4.127	3.17	0.54	3,800	4.169	4.22	1.01	0.51	17,000
23									
24									
25									
Max	4.172	4.31	0.59	9,000	4.172	4.31	1.01	0.56	24,000
Min	3.971	-0.72	0.50	1,200	3.963	-0.91	-3.87	0.47	5,000
Avg	4.074	1.86	0.53	4,164	4.092	2.30	0.44	0.51	12,447
Std	0.057	1.42	0.03	2,201	0.061	1.53	0.99	0.02	4,816
Range	0.201	5.04	0.09	7,800	0.2090	5.23	4.88	0.09	19,000

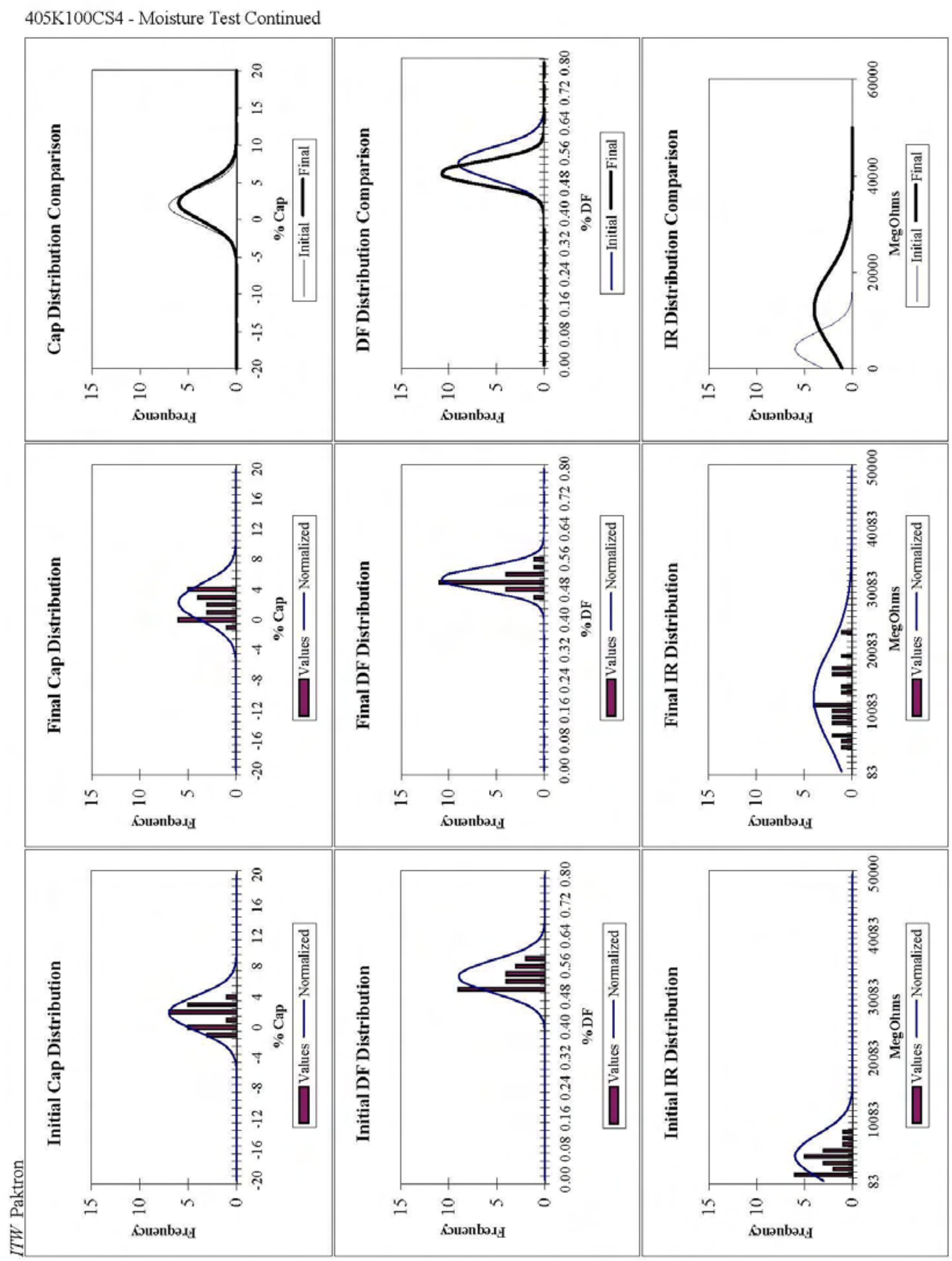
Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	7.00	3.87	√
%DF (max)	1.00	0.56	√
IR (min)	82.5	5,000	√

Notes:

Test parts successfully meet performance criteria.


405K100CS4 - Moisture Test Continued
ITW Paktron
Initial Cap Distribution
Final Cap Distribution
Cap Distribution Comparison
Initial DF Distribution
Final DF Distribution
DF Distribution Comparison
Initial IR Distribution
Final IR Distribution
IR Distribution Comparison
Frequency
% Cap
% DF
MegOhms
Values
Normalized
Initial
Final

ITW Paktron

Test File Comparison Report
106K100CB4

8/17/01

Test File Data

Tests	Code Names	Operators	Test Type
Initial	010817P005Ca	K.C.	Performance evaluation
Final	010817P005Cb	K.C.	Vibration

Test Criteria

Voltage	Temperature	%RH	Duration
			3 hours

Special: Standard CB4 units.
Tested to MIL-STD-202E, Method 204D (50g vibration testing),
except: frequency is fixed.

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	9.544	-4.56	0.44	1,800	9.548	-4.52	0.04	0.48	2,000
2	9.760	-2.40	0.57	2,500	9.756	-2.44	-0.04	0.56	2,700
3	9.629	-3.71	0.44	1,900	9.631	-3.69	0.02	0.47	2,000
4	9.657	-3.43	0.45	2,000	9.661	-3.39	0.04	0.51	2,200
5	9.957	-0.43	0.44	1,600	9.963	-0.37	0.06	0.51	1,800
6	9.689	-3.11	0.45	1,100	9.694	-3.06	0.05	0.51	1,600
7	9.780	-2.20	0.45	1,500	9.784	-2.16	0.04	0.49	1,600
8	9.733	-2.67	0.45	1,400	9.736	-2.64	0.03	0.50	1,300
9	10.212	2.12	0.49	1,700	10.213	2.13	0.01	0.49	1,500
10	9.712	-2.88	0.43	1,900	9.713	-2.87	0.01	0.50	2,000
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
Max	10.212	2.12	0.57	2,500	10.213	2.13	0.06	0.56	2,700
Min	9.544	-4.56	0.43	1,100	9.548	-4.52	-0.04	0.47	1,300
Avg	9.767	-2.33	0.46	1,740	9.770	-2.30	0.03	0.50	1,870
Std	0.180	1.80	0.04	361	0.180	1.80	0.03	0.02	382
Range	0.668	6.68	0.14	1,400	0.6650	6.65	0.10	0.09	1,400

Conclusion

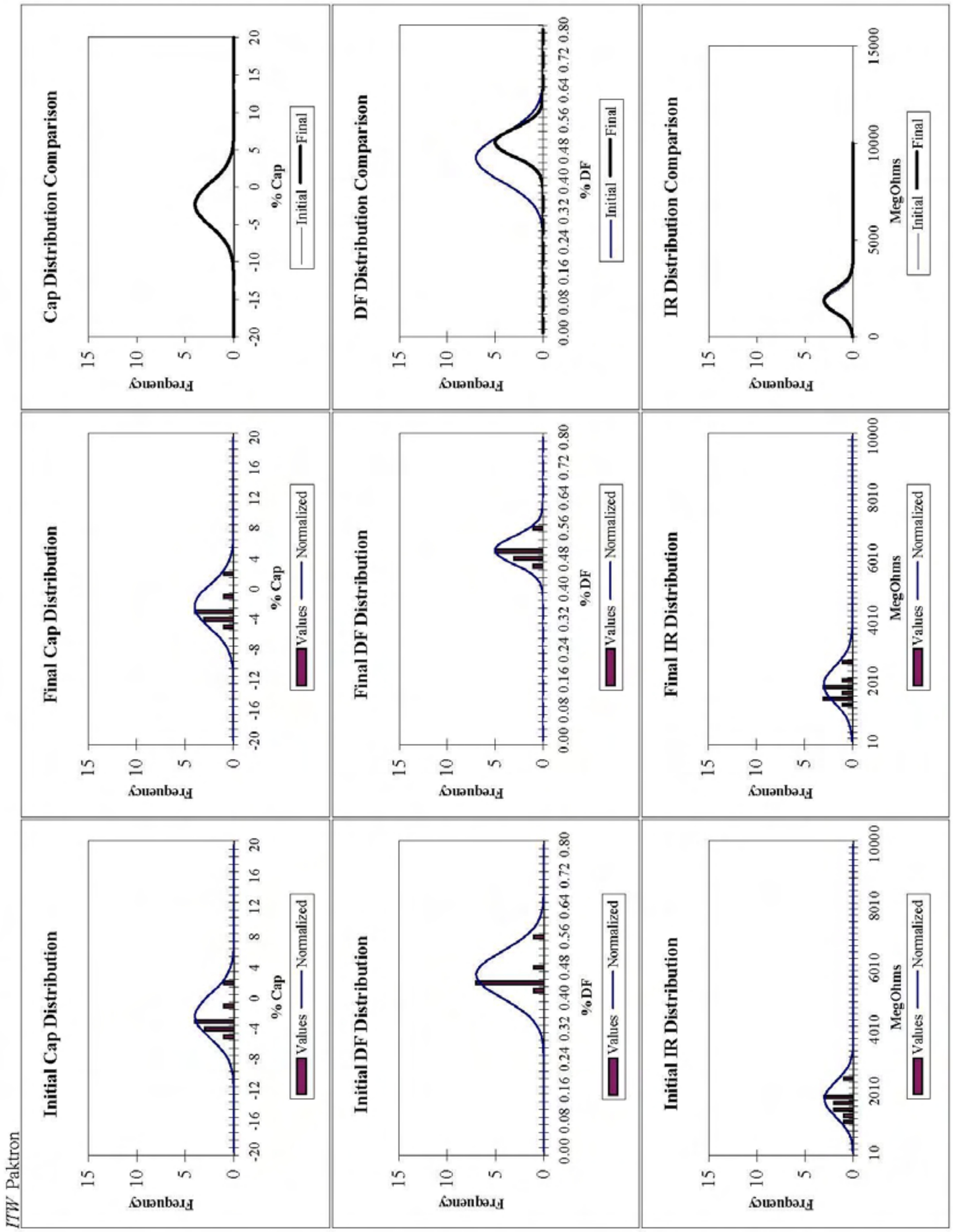
Performance:

	Pass
Test Units remained secure in enclosures.	√
Leads remained fastened to test units.	√
No sign of test induced physical deformity.	√

Notes:

Test parts successfully meet performance criteria.

106K100CB4 - Vibration Test Continued



ITW Paktron

Test File Comparison Report
405K100CS4

6/29/01

Test File Data

Tests	Code Names	Operators	Test Type
Initial	010629P005Ca	K.C.	Performance evaluation
Final	010629P005Cb	K.C.	Vibration

Test Criteria

Voltage	Temperature	%RH	Duration
			3 hours

Special: Standard CS4 units.
Tested to MIL-STD-202E, Method 204D (50g vibration testing),
except: frequency is fixed.

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	4.004	0.10	0.45	5,800	4.005	0.13	0.02	0.47	9,000
2	3.885	-2.87	0.45	8,000	3.887	-2.82	0.05	0.46	12,000
3	4.048	1.20	0.49	4,500	4.049	1.23	0.02	0.48	6,000
4	3.988	-0.30	0.52	3,800	3.987	-0.32	-0.03	0.51	4,800
5	3.801	-4.97	0.46	7,800	3.803	-4.92	0.05	0.47	8,500
6	3.985	-0.37	0.46	4,400	3.989	-0.27	0.10	0.50	5,200
7	4.070	1.75	0.49	2,900	4.073	1.83	0.07	0.49	4,200
8	3.759	-6.02	0.47	4,500	3.761	-5.97	0.05	0.47	6,000
9	3.798	-5.05	0.44	10,000	3.799	-5.02	0.03	0.50	13,000
10	3.932	-1.70	0.46	5,800	3.935	-1.62	0.08	0.47	7,500
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
Max	4.070	1.75	0.52	10,000	4.073	1.83	0.10	0.51	13,000
Min	3.759	-6.02	0.44	2,900	3.761	-5.97	-0.03	0.46	4,200
Avg	3.927	-1.82	0.47	5,750	3.929	-1.78	0.05	0.48	7,620
Std	0.105	2.63	0.02	2,102	0.105	2.63	0.03	0.02	2,856
Range	0.311	7.78	0.08	7,100	0.3120	7.80	0.13	0.05	8,800

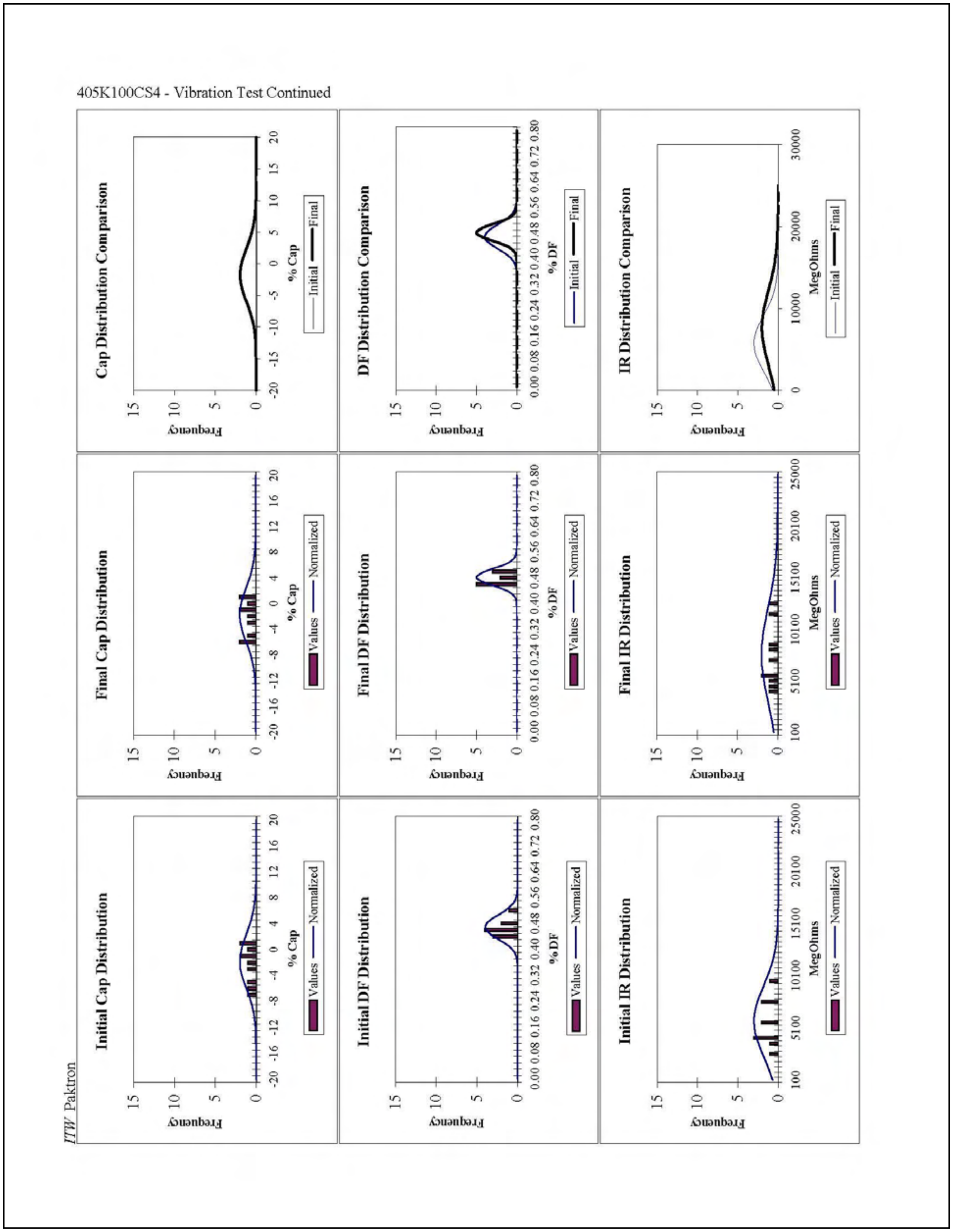
Conclusion

Performance:

	Pass
Test Units remained secure in enclosures.	√
Leads remained fastened to test units.	√
No sign of test induced physical deformity.	√

Notes:

Test parts successfully meet performance criteria.


405K100CS4 - Vibration Test Continued
ITW Paktron
Initial Cap Distribution
Final Cap Distribution
Cap Distribution Comparison
Initial DF Distribution
Final DF Distribution
DF Distribution Comparison
Initial IR Distribution
Final IR Distribution
IR Distribution Comparison
Frequency
% Cap
% DF
MegOhms
Values
Normalized
Initial
Final

Surfilm Quality Packet Contents

1. Life Testing
   a. Accelerated DC Dry Life Test (85°C / 125vdc / 2000 hrs): 105K100ST2824
   b. Accelerated DC Dry Life Test (125°C / 125vdc / 2000 hrs): 105K100ST2824
2. Moisture Resistance Testing
3. Accelerated Moisture Test (85%RH/85°C / 100vdc / 2000 hrs): 105K100ST2824
4. Thermal Shock
   a. (MIL-STD-202F, Method 107, Test Condition B-1): 105K100ST2824

ITW Paktron

Test File Comparison Report
105K100ST2824

Test File Data

Tests	Code Names	Operators	Test Type
Initial	971105P02Aa	L.P.	Performance evaluation
Final	980408P02Ea	L.P.	Dry life

Test Criteria

Voltage	Temperature	%RH	Duration
125VDC	85°C ± 3°C	NA	2000 hrs ± 12 hrs

Special: Standard ST units.
Tested to IEC 384-1, paragraph 4.23

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	1.0730	7.30	0.52	60,000	1.0630	6.30	-0.93	0.45	120,000
2	1.0720	7.20	0.51	45,000	1.0600	6.00	-1.12	0.44	100,000
3	1.0760	7.60	0.51	22,000	1.0660	6.60	-0.93	0.44	200,000
4	1.0840	8.40	0.52	30,000	1.0730	7.30	-1.01	0.43	100,000
5	1.0390	3.90	0.55	30,000	1.0290	2.90	-0.96	0.46	250,000
6	1.0450	4.50	0.53	26,000	1.0350	3.50	-0.96	0.47	150,000
7	1.0770	7.70	0.54	22,000	1.0670	6.70	-0.93	0.48	60,000
8	1.0690	6.90	0.52	30,000	1.0570	5.70	-1.12	0.48	140,000
9	1.0390	3.90	0.53	50,000	1.0280	2.80	-1.06	0.47	130,000
10	1.0540	5.40	0.49	40,000	1.0450	4.50	-0.85	0.45	100,000
11	1.0670	6.70	0.51	35,000	1.0570	5.70	-0.94	0.48	90,000
12	1.0630	6.30	0.51	30,000	1.0500	5.00	-1.22	0.48	50,000
13	1.0730	7.30	0.53	20,000	1.0630	6.30	-0.93	0.49	70,000
14	1.0740	7.40	0.48	17,000	1.0630	6.30	-1.02	0.46	200,000
15	1.0490	4.90	0.52	28,000	1.0370	3.70	-1.14	0.47	150,000
16	1.0470	4.70	0.52	30,000	1.0370	3.70	-0.96	0.48	200,000
17	1.0510	5.10	0.49	50,000	1.0430	4.30	-0.76	0.46	100,000
18	1.0780	7.80	0.51	40,000	1.0670	6.70	-1.02	0.49	60,000
19	1.0620	6.20	0.50	15,000	1.0530	5.30	-0.85	0.47	80,000
20	1.0770	7.70	0.51	45,000	1.0650	6.50	-1.11	0.50	100,000
21	1.0530	5.30	0.51	50,000	1.0430	4.30	-0.95	0.47	100,000
22	1.0580	5.80	0.49	40,000	1.0470	4.70	-1.04	0.47	180,000
23	1.0620	6.20	0.42	20,000	1.0510	5.10	-1.04	0.48	120,000
24	1.0760	7.60	0.47	40,000	1.0670	6.70	-0.84	0.45	150,000
25	1.0670	6.70	0.51	60,000	1.0550	5.50	-1.12	0.48	130,000
Max	1.0840	8.40	0.55	60,000	1.0730	7.30	-0.76	0.50	250,000
Min	1.0390	3.90	0.42	15,000	1.0280	2.80	-1.22	0.43	50,000
Avg	1.0634	6.34	0.51	35,000	1.0528	5.28	-0.99	0.47	125,200
Std	0.0131	1.31	0.03	11,799	0.0130	1.30	0.11	0.02	49,729
Range	0.0450	4.50	0.13	45,000	0.0450	4.50	0.46	0.07	200,000

Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	5.00	1.22	√
%DF (max)	1.00	0.50	√
IR (min)	500	50,000	√

Notes:

Test parts successfully meet performance criteria.

ITW Paktron

Test File Comparison Report
105K100ST2824

Test File Data

Tests	Code Names	Operators	Test Type
Initial	980303P08Aa	L.P.	Performance evaluation
Final	980415P08Da	L.P.	Dry life

Test Criteria

Voltage	Temperature	%RH	Duration
125VDC	125°C ± 3°C	NA	1000 hrs ± 12 hrs

Special: Standard ST units.
Tested to IEC 384-1, paragraph 4.23

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	1.0789	7.89	0.53	16,000	1.0700	7.00	-0.83	0.45	11,000
2	1.0755	7.55	0.54	12,000	1.0598	5.98	-1.46	0.45	10,000
3	1.0615	6.15	0.54	9,500	1.0510	5.10	-0.98	0.47	11,000
4	1.0930	9.30	0.54	30,000	1.0597	5.97	-3.05	0.47	8,800
5	1.0758	7.58	0.57	7,600	1.0577	5.77	-1.68	0.46	30,000
6	1.0642	6.42	0.54	30,000	1.0638	6.38	-0.04	0.47	9,500
7	1.0766	7.66	0.56	25,000	1.0800	8.00	0.32	0.46	20,000
8	1.0890	8.90	0.56	24,000	1.0618	6.18	-2.50	0.46	30,000
9	1.0930	9.30	0.56	12,000	1.0812	8.12	-1.08	0.47	24,000
10	1.0747	7.47	0.55	8,400	1.0547	5.47	-1.86	0.45	30,000
11	1.0910	9.10	0.57	15,000	1.0772	7.72	-1.27	0.47	26,000
12	1.0790	7.90	0.55	18,000	1.0412	4.12	-3.50	0.45	14,000
13	1.0619	6.19	0.58	22,000	1.0599	5.99	-0.19	0.46	23,000
14	1.0784	7.84	0.54	20,000	1.0372	3.72	-3.82	0.45	14,000
15	1.0923	9.23	0.54	28,000	1.0527	5.27	-3.63	0.46	18,000
16	1.0910	9.10	0.54	26,000	1.0520	5.20	-3.57	0.46	30,000
17	1.0930	9.30	0.58	30,000	1.0520	5.20	-3.75	0.45	26,000
18	1.0821	8.21	0.53	30,000	1.0399	3.99	-3.90	0.47	26,000
19	1.0679	6.79	0.54	27,000	1.0584	5.84	-0.89	0.47	18,000
20	1.0771	7.71	0.57	28,000	1.0823	8.23	0.48	0.47	20,000
21	1.0880	8.80	0.53	6,800	1.0523	5.23	-3.29	0.47	27,700
22	1.0930	9.30	0.53	16,000	1.0650	6.50	-2.56	0.45	12,000
23	1.0774	7.74	0.56	29,000	1.0718	7.18	-0.52	0.46	20,000
24	1.0833	8.33	0.54	11,000	1.0405	4.05	-3.95	0.45	28,000
25	1.0888	8.88	0.55	30,000	1.0589	5.89	-2.74	0.46	8,300
Max	1.0930	9.30	0.58	30,000	1.0823	8.23	0.48	0.47	30,000
Min	1.0615	6.15	0.53	6,800	1.0372	3.72	-3.95	0.45	8,300
Avg	1.0811	8.11	0.55	20,452	1.0592	5.92	-2.01	0.46	19,812
Std	0.0100	1.00	0.02	8,118	0.0128	1.28	1.45	0.01	7,574
Range	0.0315	3.15	0.05	23,200	0.0451	4.51	4.43	0.02	21,700

Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	5.00	3.95	√
%DF (max)	1.00	0.47	√
IR (min)	500	8,300	√

Notes:

Test parts successfully meet performance criteria.

ITW Paktron

Test File Comparison Report
105K100ST2824

Test File Data

Tests	Code Names	Operators	Test Type
Initial	970611P06Aa	L.P.	Performance evaluation
Final	970903P06Ea	L.P.	Moisture Resistance

Test Criteria

Voltage	Temperature	%RH	Duration
100	85°C	85%	2000 hours

Special: Standard ST units.
Tested to IEC 68-2-3 (steady state moisture resistance test),
except: 85°C instead of 40°C, 85%RH instead of 95% and 83.3days instead of 56.

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	1.0980	9.80	0.57	1,000	1.0970	9.70	-0.09	0.48	4,000
2	1.0540	5.40	0.55	1,100	1.0610	6.10	0.66	0.56	13,000
3	1.0510	5.10	0.53	2,200	1.0590	5.90	0.76	0.47	5,000
4	1.0540	5.40	0.51	4,000	1.0630	6.30	0.85	0.51	17,000
5	1.0720	7.20	0.51	1,500	1.0800	8.00	0.75	0.51	12,000
6	1.0740	7.40	0.58	8,000	1.0700	7.00	-0.37	0.51	16,000
7	1.0820	8.20	0.50	2,000	1.0900	9.00	0.74	0.49	15,000
8	1.0790	7.90	0.51	7,000	1.0850	8.50	0.56	0.50	13,000
9	1.0550	5.50	0.51	4,500	1.0620	6.20	0.66	0.49	5,000
10	1.0630	6.30	0.52	1,500	1.0700	7.00	0.66	0.50	16,000
11	1.0760	7.60	0.53	7,000	1.0840	8.40	0.74	0.50	15,000
12	1.0820	8.20	0.57	3,000	1.0900	9.00	0.74	0.53	18,000
13	1.0900	9.00	0.57	5,000	1.0980	9.80	0.73	0.54	14,000
14	1.0740	7.40	0.54	2,400	1.0830	8.30	0.84	0.52	20,000
15	1.0880	8.80	0.51	3,000	1.0960	9.60	0.74	0.52	16,000
16	1.0890	8.90	0.51	7,000	1.0970	9.70	0.73	0.51	22,000
17	1.0770	7.70	0.51	4,500	1.0850	8.50	0.74	0.50	12,000
18	1.0630	6.30	0.52	4,000	1.0680	6.80	0.47	0.51	14,000
19	0.9459	-5.41	0.59	8,000	0.9554	-4.46	1.00	0.51	12,000
20	1.0450	4.50	0.51	1,100	1.0530	5.30	0.77	0.49	14,000
21	1.0850	8.50	0.54	5,000	1.0430	4.30	-3.87	0.52	15,000
22	1.0860	8.60	0.54	5,500	1.0970	9.70	1.01	0.51	16,000
23									
24									
25									
Max	1.0980	9.80	0.59	8,000	1.0980	9.80	1.01	0.56	22,000
Min	0.9459	-5.41	0.50	1,000	0.9554	-4.46	-3.87	0.47	4,000
Avg	1.0674	6.74	0.53	4,014	1.0721	7.21	0.45	0.51	13,818
Std	0.0301	3.01	0.03	2,275	0.0300	3.00	0.99	0.02	4,366
Range	0.1521	15.21	0.09	7,000	0.1426	14.26	4.88	0.09	18,000

Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	7.00	3.87	√
%DF (max)	1.00	0.56	√
IR (min)	333	4,000	√

Notes:

Test parts successfully meet performance criteria.

ITW Paktron

Test File Comparison Report
105K100ST2824

Test File Data

Tests	Code Names	Operators	Test Type
Initial	970426P04Aa	L.P.	Performance evaluation
Final	970513P04Ba	L.P.	Thermal Shock

Test Criteria

Voltage	Temperature	%RH	Duration
0	-45°C to 150°C	NA	25 cycles

Special: Standard ST units.
Tested to Mil-Std-202F, Method 107, Test condition B-1,
except: -45°C instead of -50°C and 150°C instead of 125°C.

Test Data

	Initial				Final				
	Cap		DF	IR	Cap			DF	IR
Unit #	mfds	%Nom.	%	MegOhms	mfds	%Nom.	% Δ	%	MegOhms
1	1.0570	5.70	0.50	40,000	1.0580	5.80	0.09	0.48	15,000
2	1.0450	4.50	0.48	36,000	1.0430	4.30	-0.19	0.48	16,000
3	1.0760	7.60	0.49	50,000	1.0760	7.60	0.00	0.48	15,000
4	1.0470	4.70	0.49	60,000	1.0470	4.70	0.00	0.49	10,000
5	1.0810	8.10	0.49	70,000	1.0810	8.10	0.00	0.49	9,000
6	1.0800	8.00	0.48	3,600	1.0770	7.70	-0.28	0.48	4,200
7	1.0870	8.70	0.48	60,000	1.0860	8.60	-0.09	0.49	12,000
8	1.0710	7.10	0.50	22,000	1.0710	7.10	0.00	0.49	18,000
9	1.0790	7.90	0.49	60,000	1.0760	7.60	-0.28	0.48	10,000
10	1.0770	7.70	0.49	60,000	1.0760	7.60	-0.09	0.50	12,000
11	1.0774	7.74	0.49	50,000	1.0747	7.47	-0.25	0.49	9,300
12	1.0581	5.81	0.48	20,000	1.0584	5.84	0.03	0.48	12,000
13	1.0593	5.93	0.49	38,000	1.0585	5.85	-0.07	0.50	10,000
14	1.0479	4.79	0.50	38,000	1.0485	4.85	0.06	0.50	14,000
15	1.0677	6.77	0.48	22,000	1.0681	6.81	0.04	0.49	12,000
16	1.0784	7.84	0.49	70,000	1.0774	7.74	-0.10	0.49	7,000
17	1.0892	8.92	0.48	61,000	1.0884	8.84	-0.07	0.49	11,000
18	1.0622	6.22	0.48	63,000	1.0597	5.97	-0.23	0.49	12,000
19	1.0585	5.85	0.49	17,000	1.0564	5.64	-0.20	0.50	9,500
20	1.0858	8.58	0.50	70,000	1.0842	8.42	-0.15	0.48	12,000
21	1.0667	6.67	0.48	65,000	1.0661	6.61	-0.05	0.49	16,000
22	1.0404	4.04	0.49	14,000	1.0402	4.02	-0.02	0.48	14,000
23	1.0451	4.51	0.50	45,000	1.0424	4.24	-0.26	0.49	14,000
24	1.0447	4.47	0.49	25,000	1.0419	4.19	-0.27	0.49	18,000
25	1.0828	8.28	0.49	25,000	1.0805	8.05	-0.22	0.50	6,500
Max	1.0892	8.92	0.50	70,000	1.0884	8.84	0.09	0.50	18,000
Min	1.0404	4.04	0.48	3,600	1.0402	4.02	-0.28	0.48	4,200
Avg	1.0666	6.66	0.49	43,384	1.0655	6.55	-0.10	0.49	11,940
Std	0.0150	1.50	0.007	19,931	0.0150	1.50	0.12	0.007	3,380
Range	0.0489	4.89	0.02	66,400	0.0483	4.83	0.37	0.02	13,800

Conclusion

Performance:

	Design Limits	Test Data	Pass
% Δ Cap (max)	5.00	0.28	√
%DF (max)	1.00	0.50	√
IR (min)	500	4,200	√

Notes:

Test parts successfully meet performance criteria.

APPENDIX A

ITW Paktron System Summary

Company Overview

In existence since 1953 and an integral part of its parent company, ITW (Illinois Tool Works Inc.), since 1960, Paktron is one of the oldest capacitor manufacturers in the US. ITW is a $16.0+ billion diversified manufacturer of highly engineered components and industrial systems and consumables. ITW consists of approximately 825 decentralized operations in 52 countries and employs some 60,000 people. Paktron is the technological leader in the manufacture of multilayer polymer film capacitors and sells across diverse markets including automotive, commercial, Hi-Rel, military, space, and telecommunications. As a quality conscience company, Paktron follows the proven philosophy of building quality into its products. Inherent quality provides for both long-term reliability as well as outstanding product performance. Paktron's longevity is testament to its commitment to Quality.

Quality System Overview

Because of Paktron's multi-industry sales markets, rather than attempting to maintain registrations to each of the vast assortment of standardized qualty sytems specific to each of these markets, since 1953 Paktron has utilized an ever evolving, capacitor industry specific, documented quality system of its own which equals or exceeds the requirements of market oriented, standardized systems without the limitations imposed by market standardization. Paktron's Quality Assurance System is a full-featured system giving Paktron the ability to produce the finest products possible. The system includes, but is not limited to:

1. Operator Training
2. Receiving Inspection
3. Calibration
4. Out-going Inspection
5. Failure Analysis
6. Statistical Process Control
7. New Product/Process Authorization
8. Vender Qualification
9. Material Review
10. In-Process Inspections
11. Surveillance Testing
12. Qualification Testing
13. Reliability Testing

Documentation System

The Paktron documentation system strictly follows the guidelines as outlined in ISO-900x. The documentation system is separated into three different sections:

1) Procedure manuals:
   - a) Quality Manual
   - b) Document Control Procedures Manual
   - c) Accounting Procedures Manual
   - d) Engineering Procedures Manual
   - e) Marketing and Sales Procedures Manual
   - f) Purchasing Procedures Manual
   - g) Production Control Procedures Manual
   - h) Quality Control Procedures Manual
   - i) Shipping and Receiving Procedures Manual
   - j) Supplier Quality Assurance Procedures Manual
   - k) Test and Reliability Procedures Manuals

2) General Procedures:

3) Specification systems:
   - a) Assembly Specifications
   - b) Design Specifications
   - c) Equipment Specifications
   - d) Material Specifications
   - e) Process Specifications
   - f) Quality Specifications

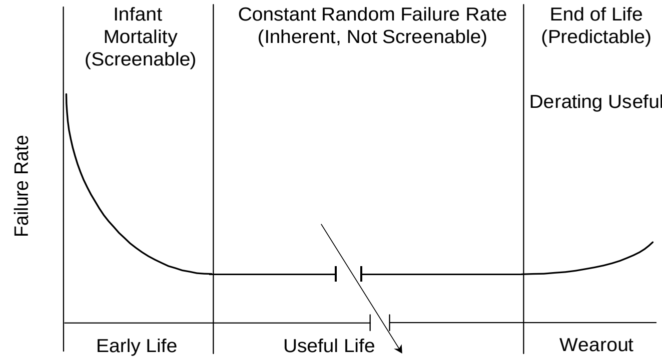
Statistical Process Control

Like many other manufacturers, in order to meet the changing quality needs of its various customers, Paktron has long ago implemented a program of Statistical Process Control (SPC). This program placed the responsibility for quality directly on the production operators who must build quality into the product rather than trying to test defects out in the final test operations. This results in the production of more consistent quality and performance products. Day-to-day process control is being done with process control charts (X bar and R, percent defective, histograms and range charts) with the Paktron QA department moving into an overview function of doing trending analysis, process averaging, specification compliance control, etc. Using these systems of certification, quality levels in the low PPMs becomes not just a goal, but a reality.

Reliability

Paktron's Quality Assurance does not end once the product has been shipped to the customer. The long-term reliability of the product is as important as its initial implementation. Theoretically, a well-designed, well-engineered, thoroughly tested and properly applied component should "never" fail in operation (within the life of the equipment). However, practical experience shows that even the best design, manufacturing, and engineering efforts do not completely eliminate the occurrence of "field" failures. Usually, field failure categories encountered in components are the "infantile", "random", and in the case of mis-application, "wearout". Paktron eliminates the "infantile" category through extensive testing and strict controls (QA/SPC). The "wearout" category is eliminated by "guard-banding" the performance characteristics of the products and by maintaining close contacts between the Paktron and customer Engineering groups. "Random" failures occur after the infant mortality stage. They occur because of "undetectable" weaknesses in the products. Although the time of occurrence of random failures cannot be predicted, the probability of occurrence or non-occurrence of such failures can be calculated by means of the theory of probability. Paktron's reputation for "Quality" in the Industry is based not only on its ability to eliminate "infantile" failures through strict QA controls, but also on being able to minimize "random" failures through its SPC controls which detects/eliminates heretofore "undetectable" weaknesses and significantly increases the reliability of the product. Paktron's film capacitors are so inherently reliable that use life is measured in decades rather than hours of operation. While Paktron's own rigorous accelerated testing shows theoretical PPM failure levels in the single digits, customer feedback consistently reports zero PPM failure levels.

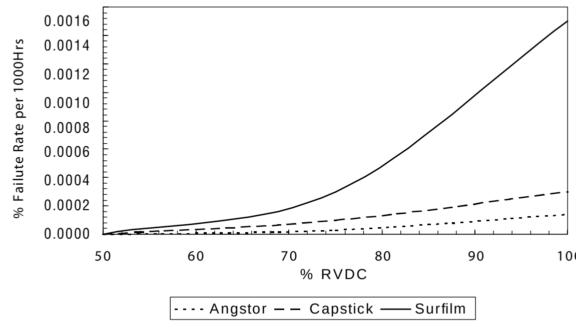
Reliability



% Failure Rate per 1000 Hours

@90% Confidence Level

	@ %RVDC and 40°C		
	50%	75%	100%
Angstor (RA)	0.0000	0.00003	0.00014
Capstick (CS, CB)	0.0000	0.00010	0.00030
Surfilm (ST)	0.0000	0.00030	0.00150



Voltage Ratings

Like all polymer film capacitors, Paktron's product offerings have "true" voltage ratings and unlike other dielectric systems require no voltage de-ratings for maximizing reliability (MTBF) or use life. With FIT rates of well under 5 FIT when used at rated voltage, these capacitors provide a positive contribution to circuit MTBF calculations. Circuit designers requiring 500 volt ratings in other dielectric systems for their 370 volt input applications are being penalized by that dielectric system's inherent deficiencies. In the polymer film capacitor industry, if a capacitor is rated at a certain voltage, then the capacitor is designed to be fully functional and reliable at that voltage for the life of the equipment. Many leading edge circuit designs take advantage of a polymer film capacitor's inherent reliability at rated voltage to both reduce board size and significantly improve performance.

Material Content

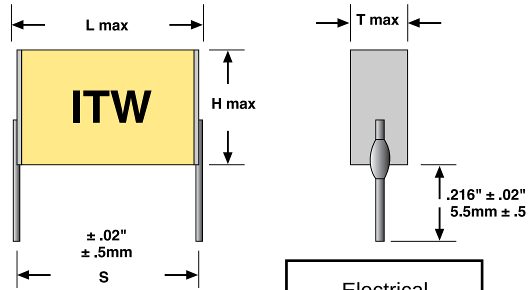
Paktron's product offerings neither contain nor are manufactured with any risk level hazardous material. The material content for polymer film capacitors is basically: polymer, aluminum, copper, tin, iron, microcrystalline polyolefin, trace amounts of other materials such as antimony and lead and various non-toxic, non-hazardous thermoplastics used for encasements. The polymers typically used are polyethylene terephthalate (PET), polyethylene napthalate (PEN) and/or polyphenylene sulfide (PPS). The products' terminations are coated (tinned) with 60Sn-40Pb to a thickness of 100-500 micro inches in order to facilitate soldering without the possibility of whisker growth while still meeting current industry guidelines for lead-free (Pb-free) with a lead (Pb) material content of under 0.1w percent (1000ppm).

APPENDIC B

Capacitor Type

RA

- **Efficient size**
- **Rugged construction**
- **Does not fail short – Self healing**
- **Low ESR/ESL**
- **No entrapped moisture or air in self-encased design**
- **No dissimilar metals to chemically degrade or attract moisture**
- **High dv/dt**
- **Wave solderable**
- **Operating temperature range: –55°C to +125°C**
- **Made in U.S.A.**



Electrical Schematic
Non-polarized

100 VDC / 80 VAC

PF Code	Value µF	L MAX	T MAX	H MAX	S ±.02 (.5)	d	Max dv/dt (V/µs)	Case	Part Number
224	.22	.350 (8.9)	.155 (3.9)	.280 (7.1)	.295 (7.5)	.025 (.6)	75	RA3	224K100RA3 _ _
474	.47	.350 (8.9)	.180 (4.6)	.305 (7.7)	.295 (7.5)	.025 (.6)	65	RA3	474K100RA3 _ _
105	1.0	.450 (11.4)	.175 (4.4)	.285 (7.2)	.394 (10)	.025 (.6)	35	RA4	105K100RA4 _ _
225	2.2	.350 (8.9)	.250 (6.3)	.350 (8.9)	.295 (7.5)	.025 (.6)	25	RA3	**225K100RA3** _ _
225	2.2	.450 (11.4)	.205 (5.2)	.285 (7.2)	.394 (10)	.025 (.6)	25	RA4	**225K100RA4** _ _
335	3.3	.450 (11.4)	.250 (6.3)	.350 (8.9)	.394 (10)	.025 (.6)	25	RA4	**335K100RA4** _ _
405	4.0	.450 (11.4)	.200 (5.1)	.380 (9.7)	.394 (10)	.032 (.8)	20	RA4	**405K100RA4** _ _
505	5.0	.450 (11.4)	.220 (5.6)	.480 (12.2)	.394 (10)	.032 (.8)	20	RA4	**505K100RA4** _ _
106	10.0	.650 (16.5)	.260 (6.6)	.460 (11.7)	.591 (15)	.032 (.8)	13	RA6	**106K100RA6** _ _

250 VDC / 160 VAC

PF Code	Value µF	L MAX	T MAX	H MAX	S ±.02 (.5)	d	Max dv/dt (V/µs)	Case	Part Number
104	.1	.450 (11.4)	.160 (4.1)	.255 (6.5)	.394 (10)	.025 (.6)	100	RA4	104K250RA4 _ _
224	.22	.450 (11.4)	.190 (4.8)	.305 (7.7)	.394 (10)	.025 (.6)	75	RA4	224K250RA4 _ _
334	.33	.450 (11.4)	.250 (6.3)	.330 (8.4)	.394 (10)	.025 (.6)	75	RA4	334K250RA4 _ _
474	.47	.450 (11.4)	.210 (5.3)	.305 (7.7)	.394 (10)	.025 (.6)	55	RA4	**474K250RA4** _ _
474	.47	.650 (16.5)	.230 (5.8)	.340 (8.6)	.591 (15)	.032 (.8)	50	RA6	474K250RA6 _ _
105	1.0	.650 (16.5)	.240 (6.1)	.340 (8.6)	.591 (15)	.032 (.8)	35	RA6	**105K250RA6** _ _

Dimensions in inches, metric (mm) in parenthesis.

Tolerance: K (±10%) standard, J (±5%) available

RoHS part number information:
No suffix indicates RoHS-5 compliant standard part number. RoHS-5 product does not contain five of the RoHS banned materials (Hg, CrVI, Cd, PBB and PBDE) in levels exceeding the industry defined limits. Component lead wires are plated with Sn / Pb and match conventional SnPb board assembly requirements.
For a RoHS-6 compliant part, add a –F? suffix, with the ? assigned at time of order/quote. RoHS-6 product does not contain any of the six RoHS banned materials (Hg, CrVI, Cd, PBB, PBDE and Pb) in levels exceeding the industry defined limits. Component lead wires are plated with Sn.

400 VDC / 250 VAC

PF Code	Value µF	L MAX	T MAX	H MAX	S ±.02 (.5)	d	Max dv/dt (V/µs)	Case	Part Number
224	.22	.650 (16.5)	.230 (5.8)	.340 (8.6)	.591 (15)	.032 (.8)	65	RA6	224K400RA6 _ _
474	.47	.650 (16.5)	.290 (7.4)	.440 (11.1)	.591 (15)	.032 (.8)	120	RA6	474K400RA6 _ _

500 VDC / 250 VAC

PF Code	Value µF	L MAX	T MAX	H MAX	S ±.02 (.5)	d	Max dv/dt (V/µs)	Case	Part Number
504	.5	.650 (16.5)	.280 (7.1)	.540 (13.7)	.591 (15)	.032 (.8)	120	RA6	504K500RA6 _ _

Dimensions in inches, metric (mm) in parenthesis.

Tolerance: K (±10%) standard, J (±5%) available

RoHS part number information:
No suffix indicates RoHS-5 compliant standard part number. RoHS-5 product does not contain five of the RoHS banned materials (Hg, CrVI, Cd, PBB and PBDE) in levels exceeding the industry defined limits. Component lead wires are plated with Sn / Pb and match conventional SnPb board assembly requirements.
For a RoHS-6 compliant part, add a –F? suffix, with the ? assigned at time of order/quote. RoHS-6 product does not contain any of the six RoHS banned materials (Hg, CrVI, Cd, PBB, PBDE and Pb) in levels exceeding the industry defined limits. Component lead wires are plated with Sn.

Electrical

Capacitance Range:
0.1 µF to 10.0 µF @ 1KHz

Tolerance:
Available in ± 5%, 10% (standard), 20%

Voltage Range:
100, 250, 400, 500 VDC

Dissipation Factor:
≤ 1.0 % @ 25°C, 1KHz

Insulation Resistance:
≥ 1,000 Megohms x µF.
Need not exceed 1,000 Megohms.

Rated Voltage	≤ 100 VDC	> 100 VDC
Test Voltage	10 VDC	100 VDC

Dielectric Strength:
1.6 x RVDC, 2 seconds max.
(Bold P/Ns) 1.3 x RVDC, 2 seconds max.

Self Inductance:
2 to 6nh typical

Temperature Range:
-55°C to 125°C @ rated DC voltage.
(Bold P/Ns) –55°C to 125°C,
derate voltage 1.25% / °C above 85°C

Performance

Accelerated DC Voltage Life Test:
1,000 Hours, 85°C, 1.25 × Rated VDC
Δ C/C ≤ 5%
DF ≤ 1.0%, 1KHz, 25°C
IR ≥ 1,000 Megohm x µF.
Need not exceed 1,000 Megohms

Moisture Test:
85°C / 85% RH / 21 days
Applied Voltage: zero bias
Δ C/C ≤ 7%
DF ≤ 1.0%, 1KHz, 25°C
IR ≥ 30% of initial limit

Long Term Stability:
After 2 years storage, standard environment Δ C/C ≤ 2%

Physical

Vibration:
Mil Std 202 Method 204D

Solder Resistance:
260°C, 5 Sec. Δ C/C ≤ 2%

Construction:
Non-inductively constructed with metallized polyester dielectric (polyethylene terephthalate). Parallel plate–multilayer polymer (MLP) design.
Electrode: Aluminum metallization.

Case:
Polyester tape wrap.

Marking:
Parts are continuously marked ITW and pf code. ITW, capacitance, tolerance and working voltage are printed on container.

Packaging:
Bulk Packaging Standard.

Angstor® Capacitor Application Notes

ITW Paktron developed the highly advanced Interleaf® Technology method of capacitor manufacturing to improve device electrical properties and stability in actual use conditions. As opposed to the conventional winding method, Interleaf® Technology uses a high laminating pressure, linear stacking technology. The resulting capacitor chip is a construction hybrid resembling a multilayer ceramic capacitor in cross section, while offering all the fail-safe advantages of a stacked plastic film capacitor. We refer to the resultant parts as MLP or multilayer polymer. The Angstor® Capacitor (or RA Style) is a self-encased, metallized film capacitor which features small size, high dv/dt capability and very low ESR at high frequency.

Intended for thru-hole and wired applications, the units feature all aluminum electrodes and terminals that are pulse welded to the lead wires. The units are back impregnated with a microcrystalline polymer sealant, and require no external coatings for moisture protection. The internal layers are heavily laminated to eliminate air from the core material which improves high frequency response compared to competitive units. Operating temperature limit is extended to125 degrees C.

The following are a few examples of applications wherein the Angstor's unique features have proven desirable:

HIGH FREQUENCY SWITCHING POWER INPUTS

As the modern power converter broke the 100 KHz switching frequency barrier, the ripple voltage and RFI control components changed drastically. On the input side of 48 volt converters, a low ESR and ESL capacitor is needed in the pi filter network to control EMI generated by the switching MOSFET. Metallized film capacitors should be used because of the voltage bias and due to the unit's ability to "clear" during a high voltage event, rather than short out like a common MLC capacitor. Electrolytic (aluminum and tantalum) capacitors are not useful because of their extremely high parasitic resistance and inductance. Under ripple voltage the Angstor is stable, while ceramic capacitors increase in loss factor, creating incremental I^2R losses.

LINE AND DATA LINE NOISE SUPPRESSION

A 250 volt Angstor will not lose value due to the bias voltage and can be used on higher voltage lines as a differential noise bypass for RFI control. High input dv/dt up to 100 volts per micro second can be handled. In modems, the Angstor is a space efficient alternative to other input current control devices. Since the capacitor body is "plastic" there exists no piezoelectric emf due to input di/dt.

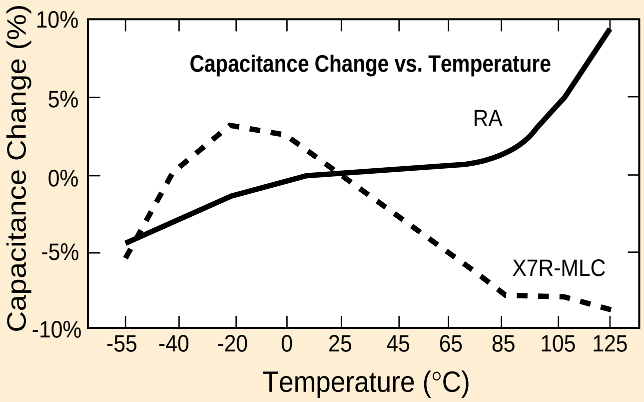
EMI/RFI SUPPRESSION

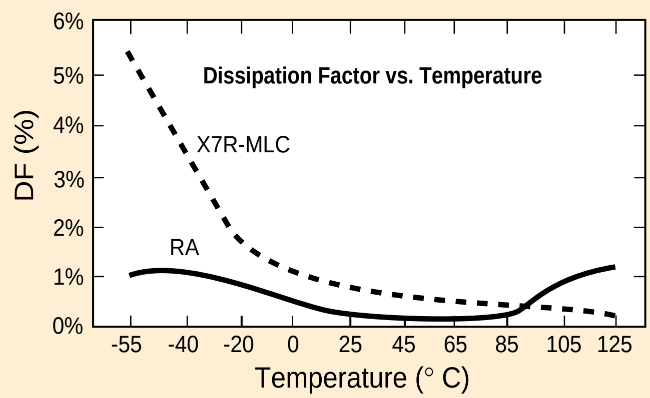
Noise suppression is required on a variety of motors and field effect devices close to the offending source to minimize RFI on the voltage bus. Noise or transients emanating from switched state motors or inductors require a low ESR capacitor as part of the filtering arrangement. The Angstor is an excellent choice for these 12, 36 and 48 volt bus-rails because of its small size compared to other film capacitors and better ESR and reliability than ceramic capacitors. As the automotive bus voltage rises from 12 to 36/42 volts, this technology will replace many ceramic and tantalum capacitors because of its enhanced voltage coefficient (stability).

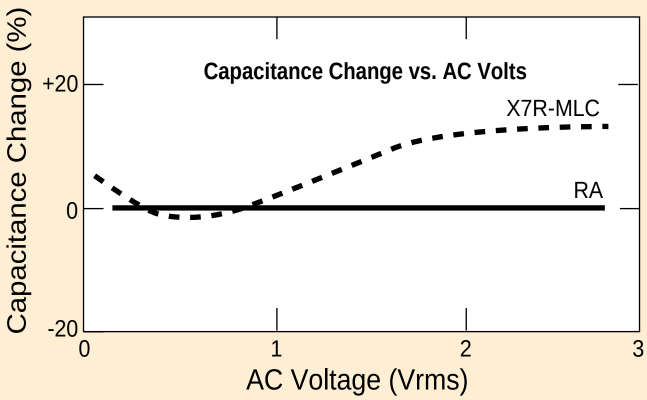
GRACEFUL AGING

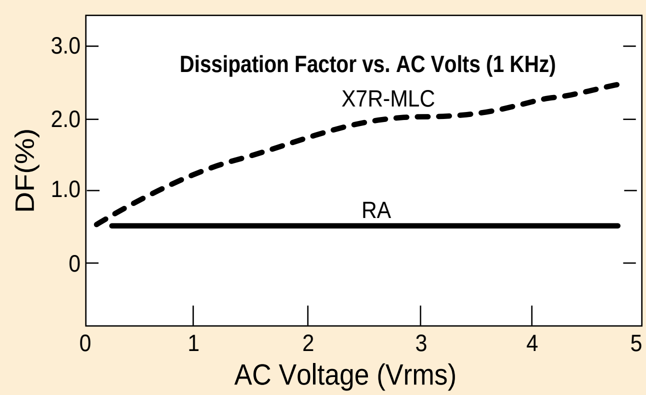
There exists no chemical interactions within the MLP Capacitor to effect long term life. The parts are suitable for 10 to 20 year life applications due to their stability and inherently low loss. The polymer dielectric becomes more crystalline over long periods of time, which can gradually lower the capacitance value. The thin-film metallized electrodes are capable of "self healing" under high voltage events. This feature avoids the shorting, cracking and rapid heat generation problem often found in ceramic capacitors.

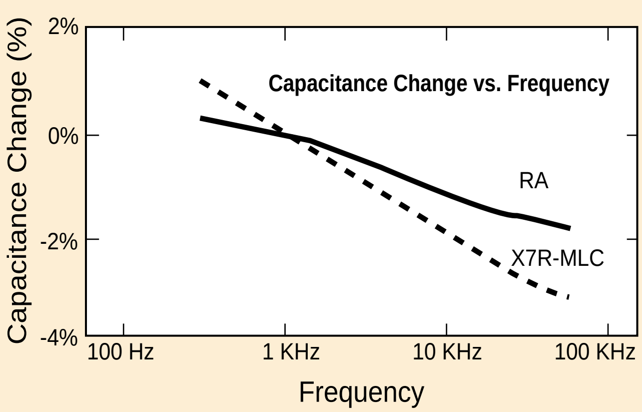
Typical Performance Curves
Comparison of Multilayer Polymer (RA) vs. Multilayer Ceramic (X7R)

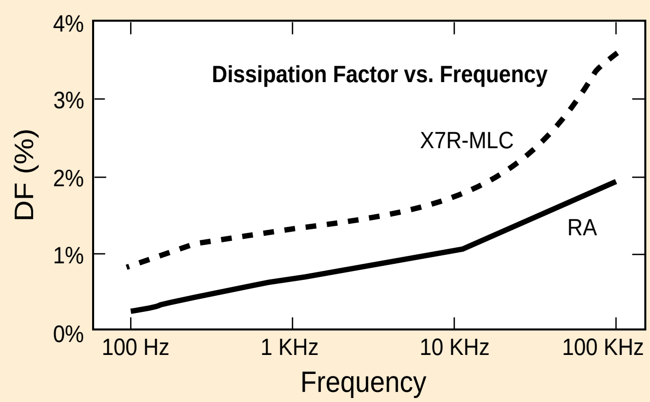


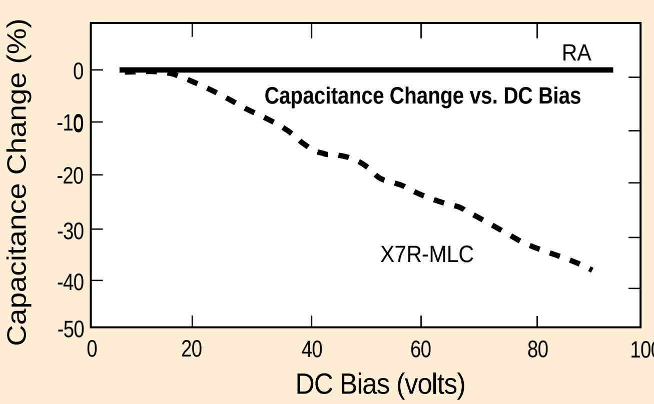


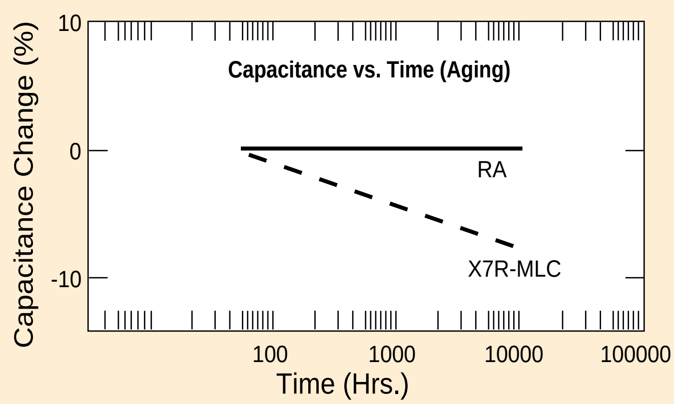






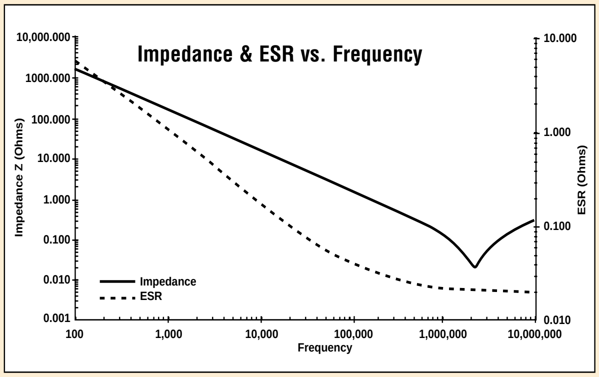




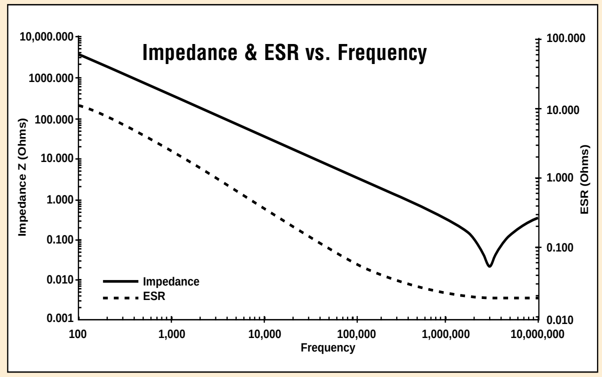


Typical Performance Curves
Selected High Value "Power" Capacitors

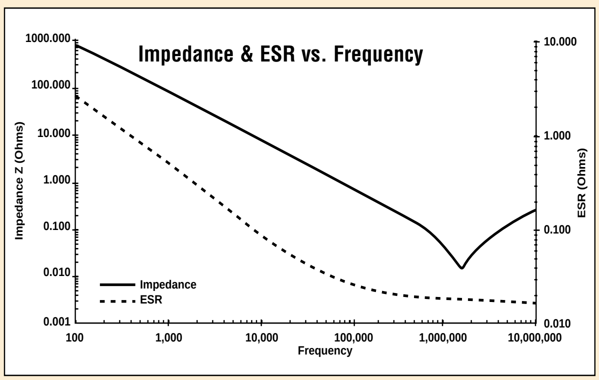
1.0 µF 100 VDC RA4



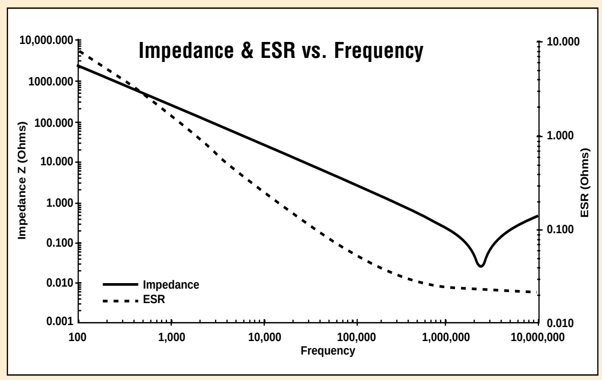
.47 µF 250 VDC RA4



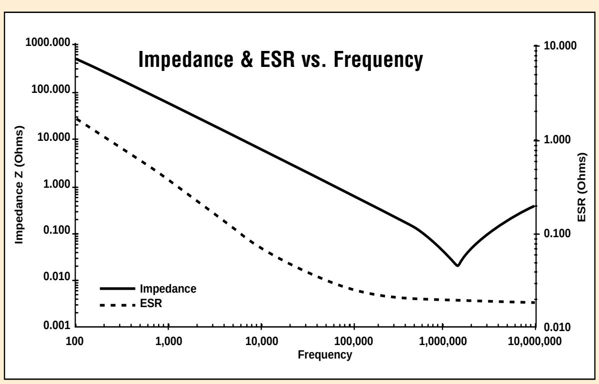
2.2 µF 100 VDC RA4



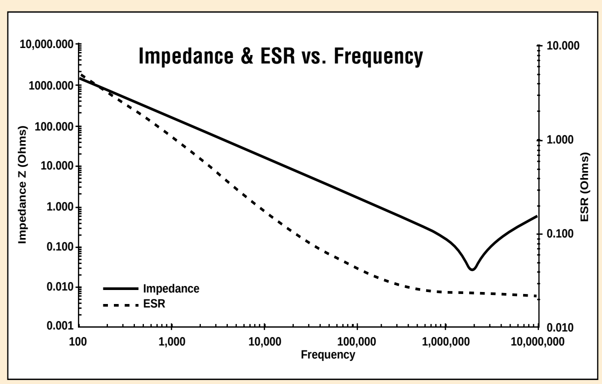
.47 µF 400 VDC RA6



3.3 µF 100 VDC RA4

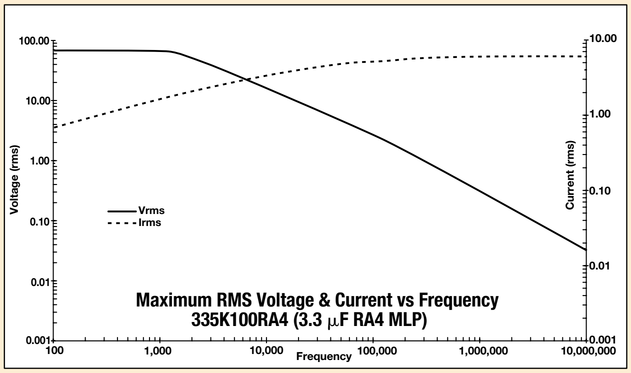


1.0 µF 250 VDC RA6

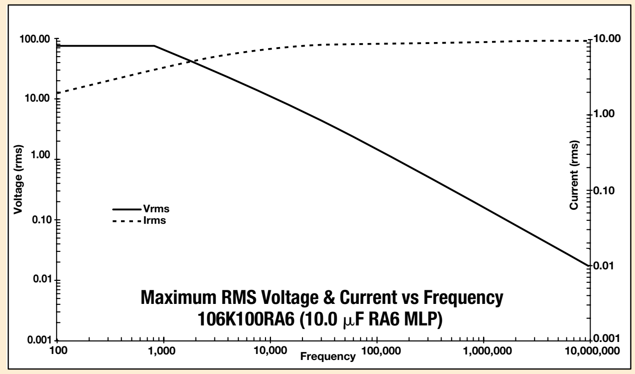


Typical Performance Curves
Selected High Value "Power" Capacitors

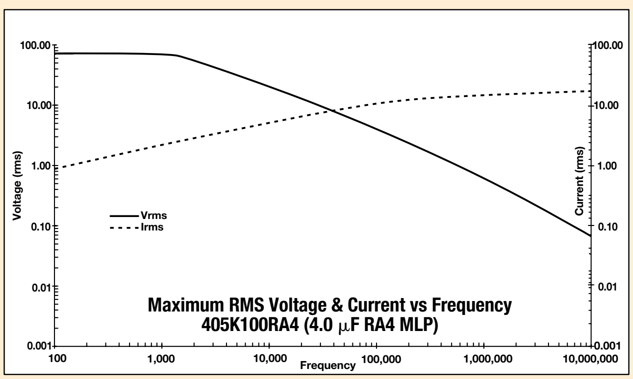
3.3 µF 100 VDC RA4



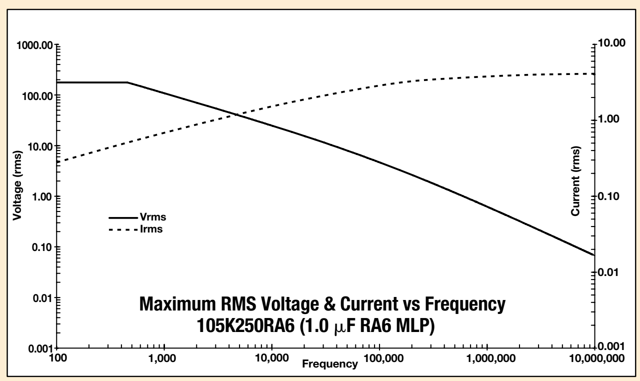
10.0 µF 100 VDC RA6



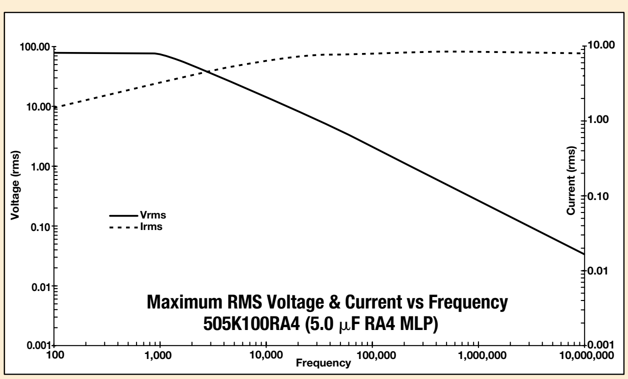
4.0 µF 100 VDC RA4



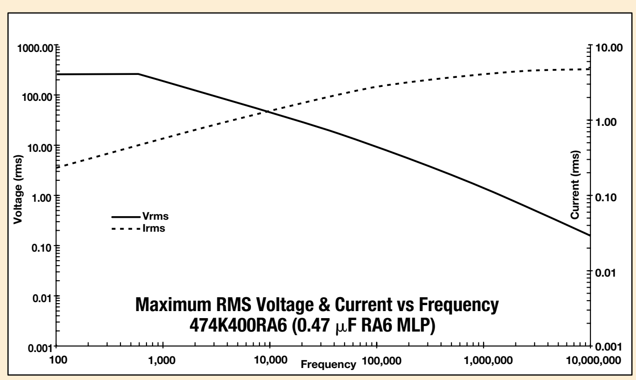
1.0 µF 250 VDC RA6



5.0 µF 100 VDC RA4



.47 µF 400 VDC RA6



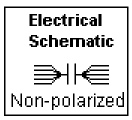
Capacitor Types

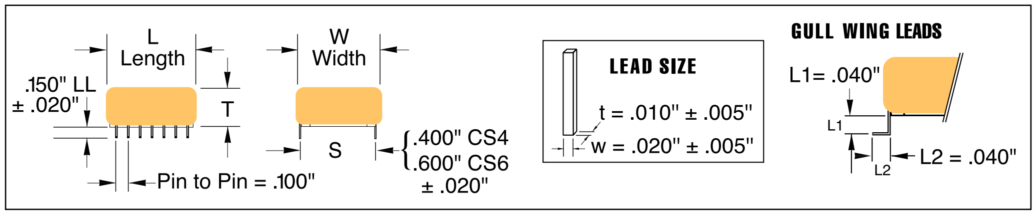
CS4
CS6

- **Surface mount capability**
- **Ideal for high frequency switching power supplies and DC to DC converters**
- **Low ESR/ESL**
- **High ripple current/ High capacitance**
- **Operating temperature range: –55°C to 125°C**
- **Volumetrically efficient**
- **Made in U.S.A.**

Voltage Ratings Note:
Like all film capacitors, Capstick capacitors have “true” voltage ratings and unlike other dielectric systems require no voltage deratings for maximizing reliability (MTBF) or use life. With FIT rates of well under 5 FIT when used at rated voltage, these units provide only a positive contribution to circuit MTBF calculations.

Circuit designers requiring 500 volt ratings in other dielectric systems for their 370 volt input applications are being penalized by that system’s inherent deficiencies. In the film capacitor industry if a device is rated at a certain voltage, then the device is designed to be fully functional and reliable at that voltage for the life of the equipment. Many leading edge circuit designs take advantage of a film capacitor’s inherent reliability at rated voltage to both reduce board size and improve performance.





50 VDC / 35 VAC

PF Code	Value µF	W MAX	T MAX	L MAX	ESR Ω @500 KHz	RMS Current @500 KHz	# Leads per side	Lead Configuration	Case	Part Number
106	10.0	.500 (12.7)	.320 (8.1)	.620 (15.7)	.003	15.3	5	Thru-hole	CS4	106K050CS4 _ _
106	10.0	.500 (12.7)	.320 (8.1)	.620 (15.7)	.003	15.3	5	SMD	CS4G	106K050CS4G _ _
206	20.0	.500 (12.7)	.320 (8.1)	1.150 (29.2)	.0025	17.8	9	Thru-hole	CS4	206K050CS4 _ _
206	20.0	.500 (12.7)	.320 (8.1)	1.150 (29.2)	.0025	17.8	9	SMD	CS4G	206K050CS4G _ _

100 VDC / 80 VAC

PF Code	Value µF	W MAX	T MAX	L MAX	ESR Ω @500 KHz	RMS Current @500 KHz	# Leads per side	Lead Configuration	Case	Part Number
205	2.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.009	8.3	3	Thru-hole	CS4	205K100CS4 _ _
205	2.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.009	8.3	3	SMD	CS4G	205K100CS4G _ _
405	4.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.007	11.5	3	Thru-hole	CS4	405K100CS4 _ _
405	4.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.007	11.5	3	SMD	CS4G	405K100CS4G _ _
475	4.7	.500 (12.7)	.250 (6.3)	.525 (13.3)	.006	12.2	3	Thru-hole	CS4	475K100CS4 _ _
475	4.7	.500 (12.7)	.250 (6.3)	.525 (13.3)	.006	12.2	3	SMD	CS4G	475K100CS4G _ _
685	6.8	.500 (12.7)	.250 (6.3)	.700 (17.8)	.005	13.7	5	Thru-hole	CS4	685K100CS4 _ _
685	6.8	.500 (12.7)	.250 (6.3)	.700 (17.8)	.005	13.7	5	SMD	CS4G	685K100CS4G _ _
106	10.0	.500 (12.7)	.250 (6.3)	.995 (25.3)	.003	15.3	7	Thru-hole	CS4	106K100CS4 _ _
106	10.0	.500 (12.7)	.250 (6.3)	.995 (25.3)	.003	15.3	7	SMD	CS4G	106K100CS4G _ _

250 VDC / 160 VAC

PF Code	Value µF	W MAX	T MAX	L MAX	ESR Ω @500 KHz	RMS Current @500 KHz	# Leads per side	Lead Configuration	Case	Part Number
105	1.0	.700 (17.8)	.300 (7.5)	.440 (11.2)	.012	5.2	3	Thru-hole	CS6	105K250CS6 _ _
105	1.0	.700 (17.8)	.300 (7.5)	.440 (11.2)	.012	5.2	3	SMD	CS6G	105K250CS6G _ _

400 VDC / 250 VAC

PF Code	Value µF	W MAX	T MAX	L MAX	ESR Ω @500 KHz	RMS Current @500 KHz	# Leads per side	Lead	Case	Part Number
334	.33	.700 (17.8)	.320 (8.1)	.435 (11.0)	.012	6.0	3	Thru-hole	CS6	334K400CS6 _ _
334	.33	.700 (17.8)	.320 (8.1)	.435 (11.0)	.012	6.0	3	SMD	CS6G	334K400CS6G _ _
474	.47	.700 (17.8)	.320 (8.1)	.460 (11.7)	.011	6.2	3	Thru-hole	CS6	474K400CS6 _ _
474	.47	.700 (17.8)	.320 (8.1)	.460 (11.7)	.011	6.2	3	SMD	CS6G	474K400CS6G _ _
105	1.0	.700 (17.8)	.320 (8.1)	.880 (22.4)	.008	9.5	7	Thru-hole	CS6	105K400CS6 _ _
105	1.0	.700 (17.8)	.320 (8.1)	.880 (22.4)	.008	9.5	7	SMD	CS6G	105K400CS6G _ _

500 VDC / 250 VAC

PF Code	Value µF	W MAX	T MAX	L MAX	ESR Ω @500 KHz	RMS Current @500 KHz	# Leads per side	Lead Configuration	Case	Part Number
474	.47	.700 (17.8)	.320 (8.1)	.625 (15.9)	.011	6.2	4	Thru-hole	CS6	474K500CS6 _ _
474	.47	.700 (17.8)	.320 (8.1)	.625 (15.9)	.011	6.2	4	SMD	CS6G	474K500CS6G _ _
105	1.0	.700 (17.8)	.320 (8.1)	1.135 (28.8)	.008	9.5	8	Thru-hole	CS6	105K500CS6 _ _
105	1.0	.700 (17.8)	.320 (8.1)	1.135 (28.8)	.008	9.5	8	SMD	CS6G	105K500CS6G _ _

Dimensions in inches, metric (mm) in parenthesis.

Tolerance: K (±10%) standard

RoHS part number information:
No suffix indicates RoHS-5 compliant standard part number. RoHS-5 product does not contain five of the RoHS banned materials (Hg, CrVI, Cd, PBB and PBDE) in levels exceeding the industry defined limits. Component lead frame pin-outs are plated with Sn / Pb and match conventional SnPb board assembly requirements.
For a RoHS-6 compliant part, add a –F? suffix, with the ? assigned at time of order/quote. RoHS-6 product does not contain any of the six RoHS banned materials (Hg, CrVI, Cd, PBB, PBDE and Pb) in levels exceeding the industry defined limits. Component lead frame pin-outs are plated with Sn.

Electrical

Capacitance Range:
0.33 µF to 20.0 µF @ 1KHz

Tolerance:
Available in K (±10%) standard

Voltage Range:
50, 100, 250, 400, 500 VDC

Dissipation Factor:
≤ 1.0 % @ 25°C, 1KHz

Insulation Resistance:
≥ 1,000 Megohms x µF.
Need not exceed 1,000 Megohms.

Rated Voltage	≤ 100 VDC	> 100 VDC
Test Voltage	10 VDC	100 VDC

Temperature Coefficient:
+6% from –55°C to 85°C

Dielectric Strength:
1.3 x rated voltage for 50/100/250/500 volt ratings.
1.6 x rated voltage for 400 volt rating

Self Inductance:
< 6nH (Typical) CS6
< 4nH (Typical) CS4

Temperature Range:
-55°C to 125°C , derate voltage 1.25% / °C above 85°C for 50/100/250 volt ratings. -55°C to 125°C, with no voltage derating for 400/500 volt ratings.

Performance

Accelerated DC Voltage Life Test:
1,000 Hours, 85°C, 1.25 × Rated VDC
Δ C/C ≤ 5%
DF ≤ 1.0%, 1KHz, 25°C
IR ≥ 1,000 Megohm × µF.
Need not exceed 1,000 Megohms

Moisture/Humidity Test:
85°C / 85% RH / 21 days
Applied Voltage: zero bias
Δ C/C ≤ 7%
DF ≤ 1.0%, 1KHz, 25°C
IR ≥ 30% of initial limit

Long Term Stability:
After 2 years storage, standard environment Δ C/C ≤ 2%

Physical

Vibration:
Mil Std 202 Method 204D

Solder Resistance:
Thru-hole wave: 260°C, 5 Sec. Δ C/C ≤ 2%
SMD reflow: 220°C, 30 Sec. Δ C/C ≤ 2%

Construction:
Non-inductively constructed with metallized polyester dielectric (polyethylene terephthalate). Parallel plate–multilayer polymer (MLP) design.
Electrode: Aluminum metallization.

Case:
UL94V-0 rated epoxy coating

Lead Frame Material:
Tinned Cu Alloy Lead Frame

Lead Spacing:
.400" (10.0mm) nominal CS4
.600" (15.0mm) nominal CS6

Marking:
ITW, type, capacitance code, tolerance code, voltage and date code

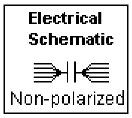
Packaging:
Anti-static tube. SMD units dry packed with desiccant in moisture barrier bag. JEDEC level on package.

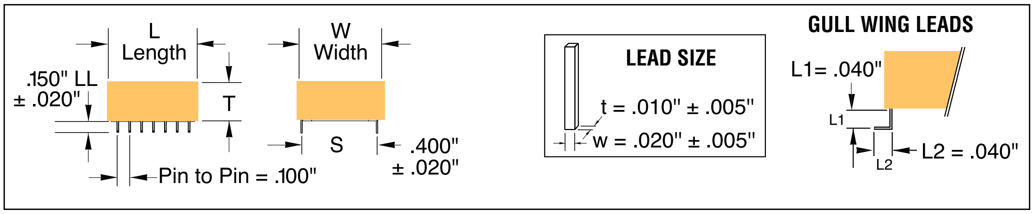
Capacitor Type

CB4

Second Generation High Frequency Switching Power Supply Capacitors

- Ideal for 48 volt bus input & output
- Low impedance (ESR/ESL) construction
- Self healing—Avoids shorts
- The reliable solution to ceramic and tantalum capacitor faults at elevated voltage
- Made for >100KHz switching power trains and reflected RFI
- Flat surface for pick and place
- Surface mount capability
- Operating temperature range: –55°C to 125°C
- High ripple current/High capacitance
- Volumetrically efficient
- Made in U.S.A.





100 VDC / 80 VAC

PF Code	Value µF	W MAX	T MAX	L MAX	ESR Ω @500 KHz	RMS Current @500 KHz	# Leads per side	Lead Configuration	Case	Part Number
205	2.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.009	8.3	3	Thru-hole	CB4	205K100CB4 _ _
205	2.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.009	8.3	3	SMD	CB4G	205K100CB4G _ _
405	4.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.007	11.5	3	Thru-hole	CB4	405K100CB4 _ _
405	4.0	.500 (12.7)	.250 (6.3)	.450 (11.4)	.007	11.5	3	SMD	CB4G	405K100CB4G _ _
475	4.7	.500 (12.7)	.250 (6.3)	.525 (13.3)	.006	12.2	3	Thru-hole	CB4	475K100CB4 _ _
475	4.7	.500 (12.7)	.250 (6.3)	.525 (13.3)	.006	12.2	3	SMD	CB4G	475K100CB4G _ _
106	10.0	.500 (12.7)	.250 (6.3)	.995 (25.3)	.003	15.3	7	Thru-hole	CB4	106K100CB4 _ _
106	10.0	.500 (12.7)	.250 (6.3)	.995 (25.3)	.003	15.3	7	SMD	CB4G	106K100CB4G _ _

Dimensions in inches, metric (mm) in parenthesis.

Tolerance: K (±10%) standard

RoHS part number information:
No suffix indicates RoHS-5 compliant standard part number. RoHS-5 product does not contain five of the RoHS banned materials (Hg, CrVI, Cd, PBB and PBDE) in levels exceeding the industry defined limits. Component lead frame pin-outs are plated with Sn / Pb and match conventional SnPb board assembly requirements.
For a RoHS-6 compliant part, add a –F? suffix, with the ? assigned at time of order/quote. RoHS-6 product does not contain any of the six RoHS banned materials (Hg, CrVI, Cd, PBB, PBDE and Pb) in levels exceeding the industry defined limits. Component lead frame pin-outs are plated with Sn.

Electrical

Capacitance Range:
2.0 µF to 10.0 µF @ 1KHz

Tolerance:
Available in K (±10%) standard

Voltage Range:
100 VDC

Dissipation Factor:
≤ 1.0 % @ 25°C, 1KHz

Insulation Resistance:
≥ 1,000 Megohms x µF.
Need not exceed 1,000 Megohms.

Rated Voltage	≤ 100 VDC
Test Voltage	10 VDC

Temperature Coefficient:
+6% from –55°C to 85°C

Dielectric Strength:
1.3 x rated voltage

Self Inductance:
< 4nH (Typical) CB4

Temperature Range:
-55°C to 125°C , derate voltage 1.25% / °C above 85°C.

Performance

Accelerated DC Voltage Life Test:
1,000 Hours, 85°C, 1.25 × Rated VDC
Δ C/C ≤ 5%
DF ≤ 1.0%, 1KHz, 25°C
IR ≥ 1,000 Megohm × µF.
Need not exceed 1,000 Megohms

Moisture/Humidity Test:
85°C / 85% RH / 21 days
Applied Voltage: zero bias
Δ C/C ≤ 7%
DF ≤ 1.0%, 1KHz, 25°C
IR ≥ 30% of initial limit

Long Term Stability:
After 2 years storage, standard environment Δ C/C ≤ 2%

Physical

Construction:
Non-inductively constructed with metallized polyester dielectric (polyethylene terephthalate). Parallel plate–multilayer polymer (MLP) design.
Electrode: Aluminum metallization.

Case:
UL94V-0 rated premolded shell

Lead Frame Material:
Tinned Cu Alloy Lead Frame

Vibration:
Mil Std 202 Method 204D

Solder Resistance:
Thru-hole wave: 260°C, 5 Sec. Δ C/C ≤ 2%
SMD reflow: 220°C, 30 Sec. Δ C/C ≤ 2%

Lead Spacing:
.400” (10.0mm) nominal CB4

Marking:
ITW, type, capacitance code, tolerance code, voltage and date code

Packaging:
Tape/Reel. 13” reel. 250 pcs/reel. Units dry packed with desiccant in moisture barrier bag. JEDEC level on package.

LOW ESR, MULTILAYER POLYMER (MLP) CAPACITORS

Miniaturized pass filters made possible by high frequency switching technology need tiny but low ESR and ESL capacitors to attenuate ripple and reflected RFI over wide frequency bands. With equivalent series resistance approaching zero, non-polar MLP Capacitors reliably sink high ripple currents in high density converters, run cool and are stable.

The trend toward distributed power management and modular power converters has driven the development of high efficiency, low profile power train components. The conventional capacitors historically used in ripple filtering applications are either too large or not suitable for popular methods of surface mounting. Electrolytic capacitors, while size efficient, do not provide the desired, stable electrical characteristics and reliability. Large value multilayer ceramic capacitors are notoriously fragile, expensive and unstable over voltage and temperature extremes. A novel but proven capacitor technology, built upon selected manufacturing techniques of multilayer ceramic and stacked, plastic film capacitors is now the preferred choice. Now film capacitor reliability can be found in chip and block shaped MLP 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. They are suitable as input and output filter capacitors in megahertz frequency switching converters, high power ballasts and inverter drives at ambient temperatures from -55° C to 125° C.

ULTRA LOW IMPEDANCE CONSTRUCTION

Figure 1 illustrates the multiple stacking technique used to make the MLP structures and the cross section which highlights similarities to stacked film and MLC construction. An all aluminum electrode and termination construction results in a low resistance and high current connection. The terminations are gathered to multiple pin lead frames for lowest ESR and ESL current handling. Low loss and frequency stable, ultra thin polyethylene-terephthalate polymer film is used as the dielectric.

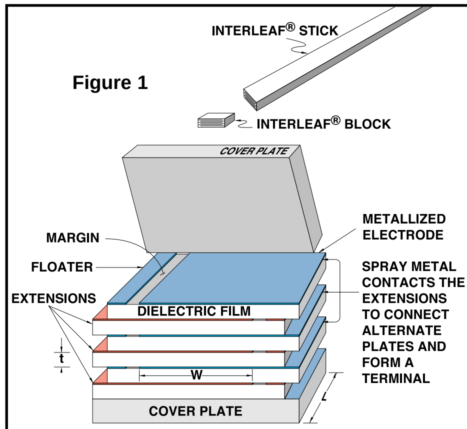
DRIVEN BY HIGH FREQUENCY POWER CONVERSION APPLICATIONS

The 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 the distributed power approaches of both telecom and computer systems, switching frequencies have risen from 20 kilohertz to between 400 KHz and 1 megahertz in 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. The MLP Capstick Capacitor can increase the series current of the converter which translates into higher wattage density at maximum efficiency.

NOTES ON USABILITY AND RELIABILITY

Because of the use of the well known PET dielectric in ultra thin sheet, the reliability of these capacitors is far better than the industry experience with electrolytic or ceramic capacitors. *There exists no capacitance drop or aging with time. The dissipation factor is stable over time.* The insulation resistance tends to get better under the influence of heat and voltage. We have shown that in-circuit problems are evident immediately and usually the result of mishandling or overheating during mounting assembly. There exist no metal leaching or dielectric diffusion mechanisms to affect the reliability over time. A complete reliability data package on this and other quality MLP capacitor styles may be obtained by contacting ITW Paktron.

Figure 1



INTERLEAF® BLOCK

$C = Kn \frac{LW}{t}$

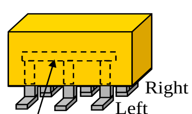
C	CAPACITANCE
K	DIELECTRIC CONSTANT
n	NUMBER OF CHARGED PLATES
L	LENGTH OF CHARGED AREA
W	WIDTH OF CHARGED AREA
t	FILM THICKNESS

MOUNTING OPTIONS

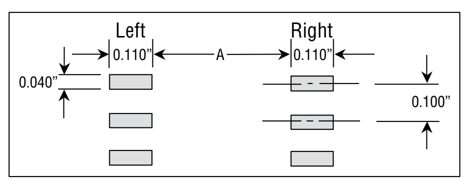
The Capstick can be conditioned for surface mounting (including IR Reflow). Leads can be trimmed to a dimension for butt or through-hole mounting, or configured as gull wing leads. See Appendix for Capstick soldering guidelines.

CS/CB Surface Mount Pad Layout

Typical Recommendations



Note: All left side capacitor leads are joined in common internal to the capacitor and all right side capacitor leads are also joined in common internal to the capacitor.



Part Number	Number of Leads per Side	A
474K500CS6G	4	0.565"
105K500CS6G	8	0.565"
334K400CS6G	3	0.565"
474K400CS6G	3	0.565"
105K400CS6G	7	0.565"
205K100CS4G, 205K100CB4G	3	0.365"
405K100CS4G, 405K100CB4G	3	0.365"
475K100CS4G, 475K100CB4G	3	0.365"
685K100CS4G	5	0.365"
106K100CS4G, 106K100CB4G	7	0.365"
106K050CS4G	5	0.365"
206K050CS4G	9	0.365"

CS/CB Performance Characteristics

over a range of -55°C to +85°C

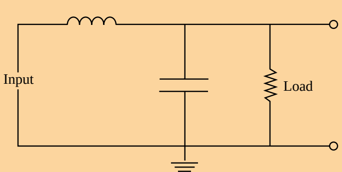
MAXIMUM RMS CURRENT (AMPS) VS. FREQUENCY

Value µF	Rated VDC	1 KHz	10 KHz	100 KHz	500 KHz	1MHz
.47	500	0.8	1.9	3.9	6.2	7.1
1.0	500	1.1	2.4	5.9	9.5	10.6
.33	400	0.7	1.3	3.5	6.0	6.9
.47	400	0.8	1.9	3.9	6.2	7.0
1.0	400	1.1	2.4	5.9	9.5	10.5
1.0	250	0.7	1.6	3.3	5.2	5.9
2.0	100	0.4	2.6	6.0	8.3	8.9
4.0	100	1.9	4.2	10.2	11.5	12.0
4.7	100	2.0	4.5	10.8	12.2	12.6
6.8	100	2.9	6.6	12.5	13.7	14.0
10.0	100	4.3	9.9	14.1	15.3	15.6
10.0	50	4.2	9.7	14.0	15.3	15.6
20.0	50	9.3	13.3	16.7	17.8	18.0

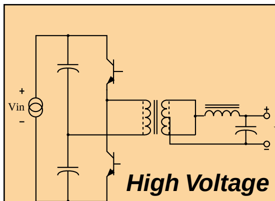
MAXIMUM RMS VOLTAGE VS. FREQUENCY

Value µF	Rated VDC	1 KHz	10 KHz	100 KHz	500 KHz	1MHz
.47	500	250	64	13.1	4.2	2.4
1.0	500	176	38	9.4	3.0	1.6
.33	400	250	64	17.2	6.9	4.0
.47	400	250	64	13.1	4.2	2.4
1.0	400	176	38	9.4	3.0	1.6
1.0	250	94	24	5.0	1.6	0.9
2.0	100	35	21	4.7	1.3	0.7
4.0	100	35	18	4.2	1.0	0.4
4.7	100	35	18	3.7	0.8	0.3
6.8	100	35	18	2.9	0.6	0.3
10.0	100	35	18	2.2	0.5	0.3
10.0	50	35	18	2.2	0.5	0.2
20.0	50	35	18	1.3	0.3	0.1

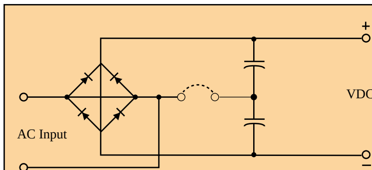
TYPICAL APPLICATIONS



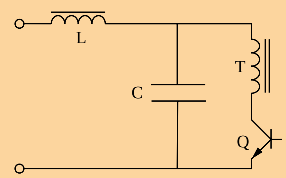
Output Filter



High Voltage Input Filter



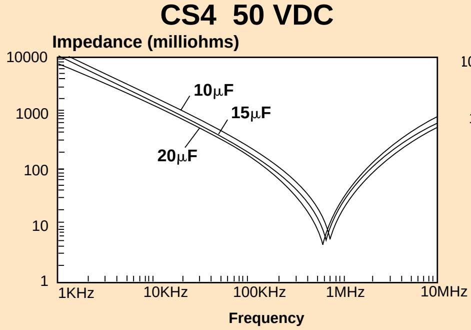
AC & Quasi AC Input Filter



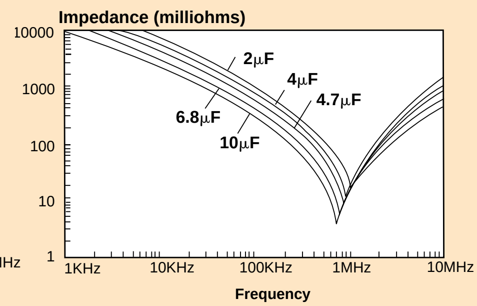
Low Pass Filter

TYPICAL IMPEDANCE VS. FREQUENCY

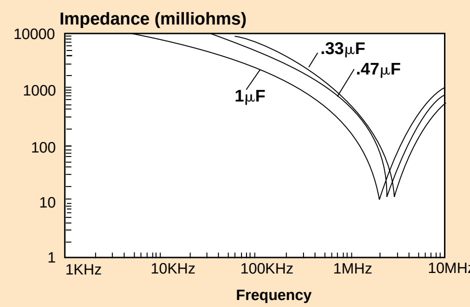
CS4 50 VDC



CS4/CB4 100 VDC

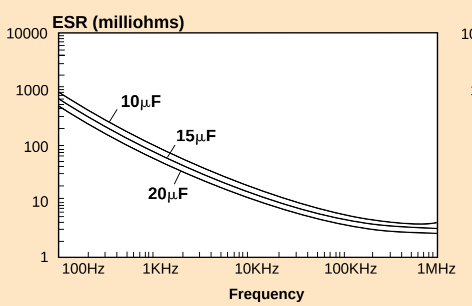


CS6 400/500 VDC

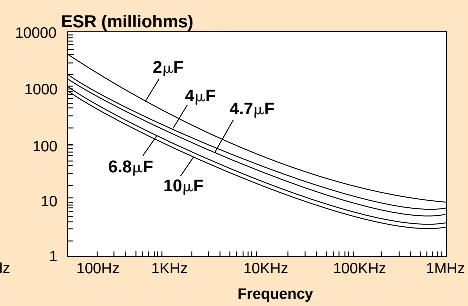


TYPICAL ESR VS. FREQUENCY

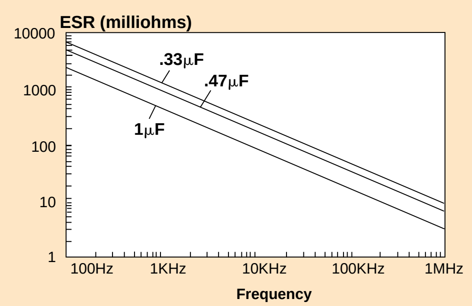
CS4 50 VDC



CS4/CB4 100 VDC



CS6 400/500 VDC



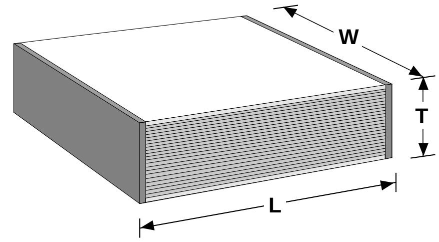
Capacitor Type

ST

Electrical Schematic
⊣⊢
Non-polarized

- **Pb free machined terminations**
- **Multilayer metallized polymer surface mount chips**
- **EIA Chip sizes**
- **Reflow solderable**
- **Made in U.S.A.**

ST2824/ST3827 CHIP STYLE



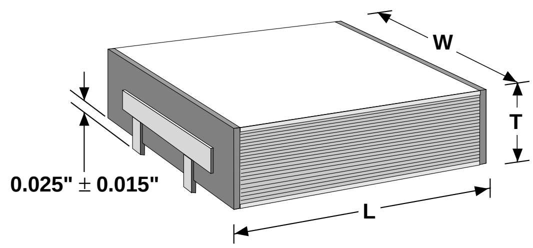
100 VDC / 80 VAC

PF Code	Value µF	L	T MAX	W MAX	Case	Part Number
105	1.0	.280 - .305 (7.1 – 7.7)	.175 (4.4)	.256 (6.5)	ST2824	105K100ST2824T
225	2.2	.380 - .405 (9.6 – 10.3)	.200 (5.1)	.286 (7.3)	ST3827	225K100ST3827T

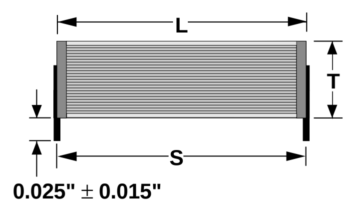
Dimensions in inches, metric (mm) in parenthesis. RoHS-6 Compliant

RoHS-6 product does not contain any of the six RoHS banned materials (Hg, CrVI, Cd, PBB, PBDE and Pb) in levels exceeding the industry defined limits

ST3/ST4 LEAD FRAME STYLE



Lead Frame Pins		
Thickness	0.010"	±0.005"
Width	0.020"	±0.005"
Pitch	0.100"	±0.015"
Height	0.025"	±0.015"
# of Pins	2	

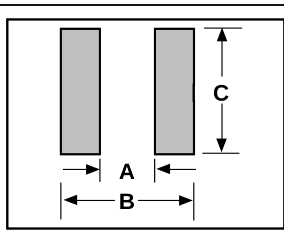


100 VDC / 80 VAC

PF Code	Value µF	L	T MAX	W MAX	Case	Part Number
105	1.0	.280 - .310 (7.1 – 7.9)	.175 (4.4)	.256 (6.5)	ST3	105K100ST3T
225	2.2	.380 - .410 (9.6 – 10.4)	.200 (5.1)	.286 (7.3)	ST4	225K100ST4T

Dimensions in inches, metric (mm) in parenthesis. RoHS-5 Compliant

RoHS-5 product does not contain five of the RoHS banned materials (Hg, CrVI, Cd, PBB, and PBDE) in levels exceeding the industry defined limits. Component lead frame pin-outs are plated with Sn /Pb and match conventional SnPb board assembly requirements



Recommended Pad Sizes (inches)			
Case Code	A	B	C
ST2824/ST3	0.210	0.365	0.275
ST3827/ST4	0.310	0.465	0.305

Surfilm® Capacitors Type ST
Performance Characteristics

Electrical

Capacitance Range	1.0 & 2.2μF @1KHz
Voltage Range	100 VDC
Tolerance	±10% (K)
Dissipation Factor	≤1.0% @ 1KHz
Insulation Resistance	≥ 1K MegOhms x μF, measured after 1 minute of electrification at 10 VDC
Dielectric Strength	1.3 x Rated Voltage
Temperature Coef.	+6.0% from -55°C to 85°C (typical)
Dielectric Absorption	0.30% (typical)
Self Inductance	6.0nH (typical) ST2824/ST3
	9.0nH (typical) ST3827/ST4

Physical

Construction
Non–inductively constructed with metallized polyester dielectric (polyethylene terephthalate). Parallel plate–multilayer polymer (MLP) design.
Electrode: Aluminum metallization

ST2824/ST3827	Chip Style Tin-based solderable surface
ST3/ST4	Lead Frame Style Tin Cu Alloy Lead Frame, "I" lead configuration for SMD butt joint mounting
Enclosure	Self-encased
Marking	Parts are not marked. ITW, capacitance code, tolerance and rated voltage are printed on container.
Temperature Range	-55°C to 125°C, derate voltage 1.25% / °C above 85°C
Packaging	Tape/Reel. Dry packed with dessicant in moisture barrier bag. JEDEC level on package.
Quantity per reel	ST2824 1200 ST3827 850 ST3 800 ST4 700

Solder Attachment

	Yes	No
Conductive Reflow	√	
Convection Reflow	√	
IR Reflow	√	
Soldering Iron (220°C)	√	
Wave Solder		√

See Soldering Guidelines Spec. for details.

Performance

Accelerated DC Voltage Life Test:

Test Conditions

Temperature	85°C ±5°C
Applied Voltage	1.25 x Rated Voltage
Test Duration	1000 hours

Performace Requirements

Capacitance	delta of ≤ 5.0%
Dissipation Factor	≤ 1.00%
Insulation Resistance	> 50% of specification

Humidity:

Test conditions

Temperature	85°C ± 5°C
Applied Voltage	Zero voltage
Humidity	85%
Test Duration	21 days

Performance Requirements

Capacitance	delta of ≤ 7.0%
Dissipation Factor	≤1.00%
Insulation Resistance	≥ 50% of specification

Solderability (Convection Reflow):

Test Conditions

Solder Temperature	220°C +0°C, -10°C
Test Duration	30 seconds ±1

Performance Requirements

Capacitance	delta of ≤ 5.0%

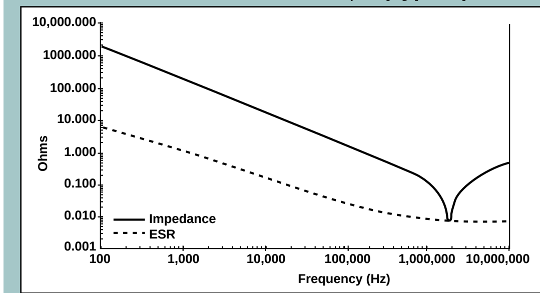
Terminal Adhesion:

0.5 Kg through hole in substrate, centered. Solder fillets ≥ 1/3 T, 5 seconds with no damage.

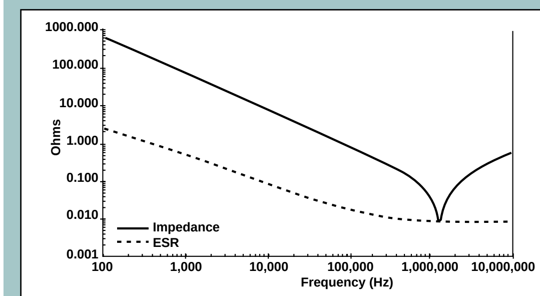
Long Term Stability:

≤ 2.0% over two years at a temperature of between 0°C and 35°C and a RH of between 35% and 65%.

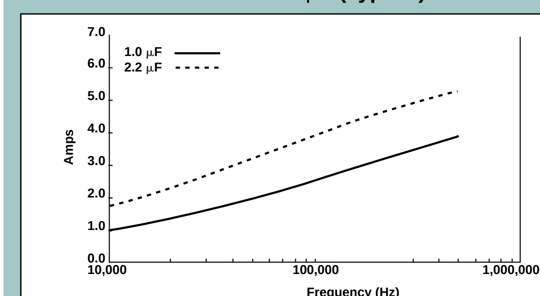
Impedance & ESR vs Frequency
ST2824/ST3 100VDC 1.0 μF (Typical)



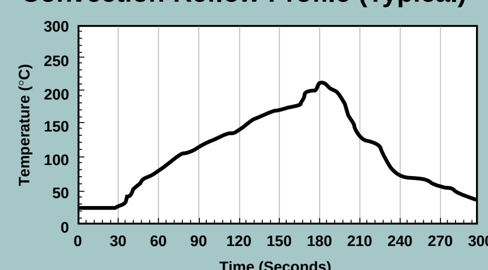
Impedance & ESR vs Frequency
ST3827/ST4 100VDC 2.2 μF (Typical)



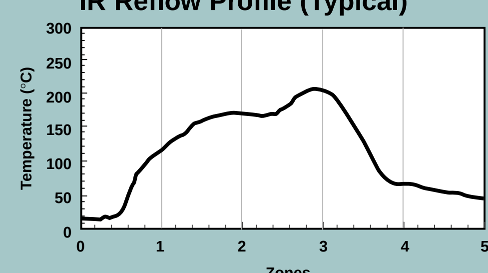
Maximum RMS Current
ST2824/ST3 1.0 μF &
ST3827/ST4 2.2 μF (Typical)



Convection Reflow Profile (Typical)



IR Reflow Profile (Typical)

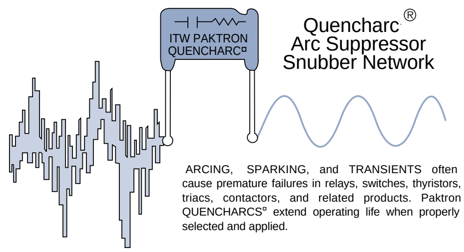


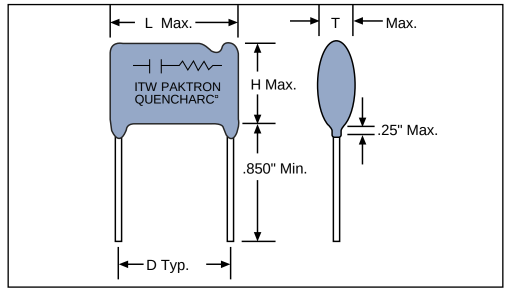
Arc Suppressor
Snubber Network

Q/QRL

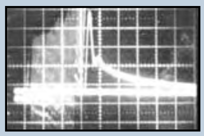
UL/CSA version

- **Relay contact protection • Noise reduction on controllers/drivers**
- **dv/dt suppression on thyristor and triacs • EMI/RFI reduction**
- **No lag time in suppression • Available voltages: 125 VAC - 660 VAC**
- **Type QRL – UL/CSA version**

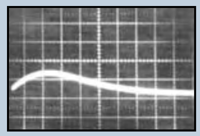




VOLTAGE WAVEFORM

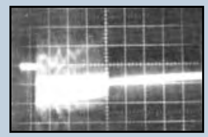


UNSUPPRESSED
100V/div .1ms/div

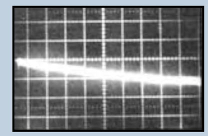


SUPPRESSED
100V/div .5ms/div

CURRENT WAVEFORM



UNSUPPRESSED
100V/div .1ms/div



SUPPRESSED
100V/div .1ms/div

PF Code	Value µF	Voltage VDC/VAC	Type	Ohms ±10%	Watt	L MAX	T MAX	H MAX	D Typical	Part Number
104	.1	600 / 250	QC	22	.5	1.08 (27.4)	.39(9.9)	.66 (16.7)	.82 (20.8)	104M06QC22
104	.1	600 / 250	QC	47	.5	1.08 (27.4)	.39(9.9)	.66 (16.7)	.82 (20.8)	104M06QC47
104	.1	600 / 250	QC	100	.5	1.08 (27.4)	.39(9.9)	.66 (16.7)	.82 (20.8)	104M06QC100
104	.1	600 / 250	QC	150	.5	1.08 (27.4)	.39(9.9)	.66 (16.7)	.82 (20.8)	104M06QC150
104	.1	600 / 250	QC	220	.5	1.08 (27.4)	.39(9.9)	.66 (16.7)	.82 (20.8)	104M06QC220
104	.1	600 / 250	QC	330	.5	1.08 (27.4)	.39(9.9)	.66 (16.7)	.82 (20.8)	104M06QC330
104	.1	1200/480	QH	39	2.0	1.60(40.6)	.64(16.3)	1.04(26.4)	1.29(32.7)	104M48QH39
104	.1	1600/660	QV	39	2.0	2.18(55.3)	.54(13.7)	1.00(25.4)	1.80(45.7)	104M66QV39
254	.25	600 / 250	QD	22	.5	1.45(36.8)	.42(10.6)	.75(19.0)	1.20(30.5)	254M06QD22
254	.25	600 / 250	QD	47	.5	1.45(36.8)	.42(10.6)	.75(19.0)	1.20(30.5)	254M06QD47
254	.25	600 / 250	QD	100	.5	1.45(36.8)	.42(10.6)	.75(19.0)	1.20(30.5)	254M06QD100
254	.25	600 / 250	QD	150	.5	1.45(36.8)	.42(10.6)	.75(19.0)	1.20(30.5)	254M06QD150
504	.5	600 / 250	QE	22	.5	1.45(36.8)	.59(15.0)	.92(23.4)	1.20(30.5)	504M06QE22
504	.5	600 / 250	QE	47	.5	1.45(36.8)	.59(15.0)	.92(23.4)	1.20(30.5)	504M06QE47
504	.5	600 / 250	QE	100	.5	1.45(36.8)	.59(15.0)	.92(23.4)	1.20(30.5)	504M06QE100
504	.5	600 / 250	QE	150	.5	1.45(36.8)	.59(15.0)	.92(23.4)	1.20(30.5)	504M06QE150
504	.5	200 / 125	QA	22	.5	1.08(27.4)	.37(9.4)	.64(16.3)	.82(20.8)	504M02QA22
504	.5	200 / 125	QA	47	.5	1.08(27.4)	.37(9.4)	.64(16.3)	.82(20.8)	504M02QA47
504	.5	200 / 125	QA	100	.5	1.08(27.4)	.37(9.4)	.64(16.3)	.82(20.8)	504M02QA100
504	.5	200 / 125	QA	220	.5	1.08(27.4)	.37(9.4)	.64(16.3)	.82(20.8)	504M02QA220
105	1.0	200 / 125	QB	22	.5	1.45(36.8)	.39(9.9)	.66(16.7)	1.20(30.5)	105M02QB22
105	1.0	200 / 125	QB	47	.5	1.45(36.8)	.39(9.9)	.66(16.7)	1.20(30.5)	105M02QB47

Dimensions in inches, metric (mm) in parenthesis.

RoHS-6 Compliant

UL/CSA Recognized Across-the-Line Application

Note: Complies with UL1414 / CSA-C22.2 No.1

104	.1	125 VAC	QRL	150	.5	1.08(27.4)	.44(11.18)	.66(16.7)	.82(20.8)	104MACQRL150
104	.1	125 VAC	QRL	680	.5	1.08(27.4)	.44(11.18)	.66(16.7)	.82(20.8)	104MACQRL680

Type QRL: UL Recognized for 125 VAC across-the-line. UL File No. E33628
CSA Certified for 125 VAC across-the-line. CSA File No. LR32208

RoHS-6 Compliant

HOW QUENCHARC® WORKS

The most popular and commonly used method of arc suppression is to connect a resistor-capacitor network as shown in Figures A and B. The preferred method of connection is across the contacts it wants to protect. However, the network can be hooked across the load, as is shown by the dashed line, when all inductance of the load circuit is considered lumped together.

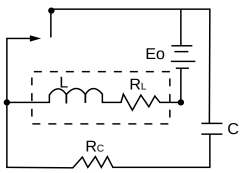


Figure A

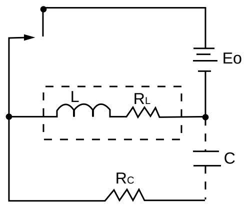


Figure B

When the contacts open, the voltage across the uncharged capacitor is zero and the transient voltage starts charging the capacitor. In the meantime, the gap of the contact is steadily widened, and by the time the capacitor is charged to its full potential, the contact gap is widened well beyond the minimum breakdown potential of air, thus preventing the arcing. When the contact closes, the inrush current from the capacitor may damage the contact, and here resistance is needed to limit the maximum current to Eo/Rc during the contact closure.

The induced voltage on opening the contact is

$$V = IR_C = \frac{R_C}{R_L} E_o \qquad (1)$$

and, as can be seen, the larger the value of a series resistor, the higher the induced voltage. On the other hand, the lower series resistance makes the current on contact closure higher. The time dependence of the voltage is given by:

$$V(t) = L\frac{di}{dt} + (R_L + R_C)i + E_o + \frac{1}{C}\int_0^t i\,dt$$

and the rate of voltage change, which is important in transient suppression of triac switching, is:

$$\frac{dv}{dt} = L\frac{d^2i}{dt^2} + (R_L + R_C)\frac{di}{dt} + \frac{i}{C}$$

Equation (3) tells us that by knowing the circuit conditions with given values of L and coil resistance that limit the current prior to contact opening, the rate of voltage rise is inversely proportional to capacitance. In other words, the larger the capacitance, the greater is the transient suppression. However, when the contact closes, the additional energy stored in the capacitor has to be discharged through the contact. Hence, a compromise has to be made in the selection of both resistance and capacitance.

In an effort to provide a simple answer to designers' requests for proper values of resistance and capacitance, some relay manufacturers came out with empirical formulas and nomographs. For instance, C.C. Bates[1] gives the equations

$$C = \frac{I^2}{10} \qquad R = \frac{E_o}{10I\left(1 + \frac{50}{E_o}\right)}$$

where
C = capacitance in µF
I = load current in amperes prior to contact opening
R = resistance in ohms in series with capacitor
E_O = source voltage

The choice of resistance and capacitance value however, is quite flexible. In fact, the choice is so simple that one does not need a nomograph at all. Besides, a nomograph published by a certain relay manufacturer may be for the particular relays the firm manufactures, not necessarily universal.

[1]Bates, C.C., "Contact Protection of Electromagnetic Relays." *Electro-mechanical Design*, August, 1966.

CHOOSING A QUENCHARC®

In choosing a Quencharc®, first of all, check the maximum switching current rating of the contacts to be protected. This value differs for different types of contact materials and different types of relays. The maximum current during the contact closure with an RC network is E_O/R_C, where E_O is the source voltage and R_C is the resistance value of the network. The quantity E_O/R_C must be lower than the maximum switching current for obvious reasons. Next, the selection of capacitance is best done with an oscilloscope.

Connect the oscilloscope probe to the relay wiper and ground the other plate of the contact. Without an RC network across the contacts, check the amplitude of the transient voltage on contact break and the amplitude of the current on contact make. If the voltage is less than 300V and the current less than the maximum switching current rating of the relay, and if you don't see any arcing, you may not need the contact protection at all. If you spot arcing, connect a .1 µF + 100 ohm, 250 VAC, QC100 (our most widely used Quencharc®), across the contacts, and observe the levels of suppression, voltage on break and current on make. The suppressed voltage should be below 250V, which provides 70 volts of safety margin from the breakdown potential of air. If the voltage is still above 250V, try a .25 µF + 220 ohms or a .5 µF + 330 ohms range. If you need a higher capacitance than 1.0 µF, you may be better off with a Zener or a varistor in terms of cost and space. For most relays and triacs .1 µF + 100 ohms provides a satisfactory suppression.

When protecting contacts in AC circuits, the same general guidelines as for DC circuits can be used, but the wattage of the resistor must be considered if current flow is sustained for a long enough period of time to heat the component. Compute the impedance of the RC unit to obtain a current value, then use I^2R and time considerations to determine whether the standard network resistor is adequate.

OPERATING

TEMPERATURE RANGE
–55°C to +85°C at full rated voltage.

DISSIPATION FACTOR
The nominal dissipation factor is determined from the following equation:
DF = 2πfCR + .006
where:
f = test frequency in hertz
C = nominal capacitance value in farads
R = nominal value of series resistor in ohms.

DIELECTRIC WITHSTANDING VOLTAGE
Unit shall withstand a DC potential of 1.6 times the DC voltage rating. Testing conducted at 25°C.

DC LIFE TEST
Unit shall withstand a test potential of 125% of the rated voltage for a period of 500 hours at a temperature of 85°C. A failure shall consist of:
- Capacitance change greater than 5%.
- Dissipation factor greater than original limits.

LONG TERM STABILITY
The capacitance shall not change more than 2% when stored at ambient temperature and humidity for a period of 2 years or less.

PHYSICAL

TOLERANCE
Capacitor ± 20%, Resistor ± 10%.

CONSTRUCTION*
Metallized polyester capacitor in series with a carbon composition resistor.

CASE
Coated with a UL94V-0 flame retardant epoxy.

WIRE LEADS
#20 AWG (.032") capacitor end. #18 AWG (.040") for QH & QV styles. Resistor end .025" to 0.045".

MARKING
ITW, Quencharc®, capacitance, resistance, voltage.

* 39 ohm resistors are power wire-wound

APPENDIX C

MLP Capacitor Advantages over Ceramics

ITW Paktron has been manufacturing film capacitors for over 50 years. Paktron and its parent, Illinois Tool Works Inc., hold in excess of seventy-five patents for film capacitors and machine design.

Paktron specializes in Ultra Low ESR multilayer polymer film capacitors and leads in Film-Chip and SMT designs. Capacitors featured are:

Angstor® Miniature Radial

Capstick® Lead-Framed MLP

Surfilm® Surface Mount Chip

Other famous lines featured are:

Quencharc® R-C Network/Snubber

The metallized electrode used in Paktron's proprietary Interleaf® Technology process assures reliable performance. Multilayer Polymer (MLP) surface mount, chip and lead framed capacitors are replacing MLC (ceramic) capacitors in higher voltage and reliability-sensitive equipment. This includes the popular -48 volt telecom bus, off-line HVAC and PFC front ends.

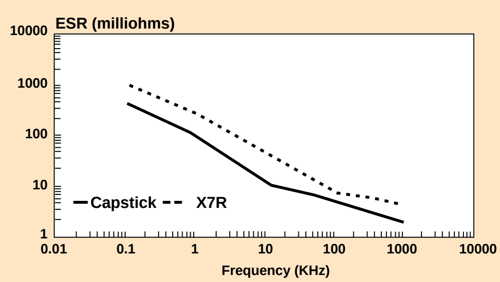
Today, the fastest-growing market segment that Paktron serves is Power Conversion for industries such as Telecommunications/Datacom, military infrastructure, automotive, medical and high-end industrial. The 100 volt rated MLP film capacitor is becoming the part of choice for input/output filtering in -48 volt telecom bus power applications (on-board or dc/dc modules). The MLP capacitor provides improved stability, both electrically and mechanically, compared to multilayer ceramics. The MLP features "non-shorting" operation and does not crack like large ceramic blocks.

Multilayer Polymer Film (MLP)	X7R Ceramic (MLC)
✔ Stable under voltage	Cap drops 40% at 100 volts bias
✔ Stable under AC voltage	DF increases with AC voltage
✔ Chip is plastic with good TCE	Body is ceramic which cracks
✔ Stable over temperature	DF increases at low temperature
✔ No aging mechanism	Cap drops per decade hour
✔ Resilient under thermal shock	Ceramic body cracks easily
✔ Self-clearing thin electrodes	Thick film electrodes fail short
✔ Stable under mechanical stress	Piezoelectric voltage sensitive
✔ Low cost	Precious metal electrodes
✔ Ultra Low ESR	Low ESR
✔ Dissipation Factor ≤ 1%	Dissipation Factor ≤ 2.5%

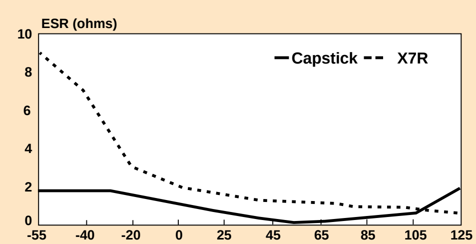
TYPICAL CHARACTERISTICS

The following graphs contrast important characteristics of MLP Capsticks to MLC ceramic units in typical, dynamic converter conditions. The electrical stability of the MLP capacitor is clear.

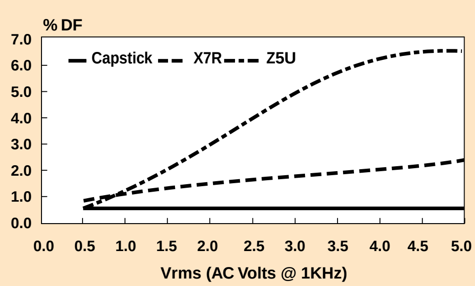
ESR vs. Frequency



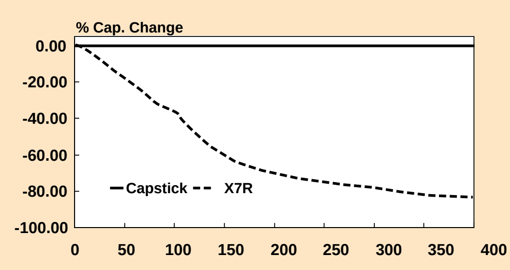
120 Hz ESR vs. Temperature



Dissipation Factor vs Vrms



Capacitance vs DC Bias



Light Weight Construction

By the very nature of the materials from which they are constructed, polymer film capacitors are a "lightweight" in terms of mass while being a "heavyweight" in terms of performance making for a combination unmatched by any other capacitor technology.

Typical Capacitor Weights per Piece

Series	Part Number	Description	Unit Weight lbs	Unit Weight grams
Angstor				
	474K250RA4	0.47µF, ±10% , 250vdc, L.S. 0.400"	0.0014	0.634
	225K100RA4	2.20µF, ±10% , 100vdc, L.S. 0.400"	0.0009	0.408
	335K100RA4	3.30µF, ±10% , 100vdc, L.S. 0.400"	0.0013	0.590
	405K100RA4	4.00µF, ±10% , 100vdc, L.S. 0.400"	0.0018	0.837
	474K400RA6	0.47µF, ±10% , 400vdc, L.S. 0.600"	0.0030	1.352
	105K250RA6	1.00µF, ±10% , 250vdc, L.S. 0.600"	0.0021	0.953
Capstick				
	405K100CB4	4.00µF, ±10% , 100vdc, L.S. 0.400"	0.0028	1.252
	475K100CB4	4.70µF, ±10% , 100vdc, L.S. 0.400"	0.0031	1.406
	106K100CB4	10.0µF, ±10% , 100vdc, L.S. 0.400"	0.0062	2.798
	405K100CS4	4.00µF, ±10% , 100vdc, L.S. 0.400"	0.0021	0.93
	475K100CS4	4.70µF, ±10% , 100vdc, L.S. 0.400"	0.0025	1.13
	106K050CS4	10.0µF, ±10% , 050vdc, L.S. 0.400"	0.0043	1.95
	106K100CS4	10.0µF, ±10% , 100vdc, L.S. 0.400"	0.0056	2.53
	206K050CS4	20.0µF, ±10% , 050vdc, L.S. 0.400"	0.0086	3.90
	334K400CS6	0.33µF, ±10% , 400vdc, L.S. 0.600"	0.0029	1.29
	474K400CS6	0.47µF, ±10% , 400vdc, L.S. 0.600"	0.0044	2.01
	105K250CS6	1.00µF, ±10% , 250vdc, L.S. 0.600"	0.0029	1.32
	105K400CS6	1.00µF, ±10% , 400vdc, L.S. 0.600"	0.0094	4.28
	105K500CS6	1.00µF, ±10% , 500vdc, L.S. 0.600"	0.0120	5.44
Surfilm				
	105K100ST2824	1.00µF, ±10% , 100vdc, L.S. 0.300"	0.0005	0.23
	225K100ST3827	2.20µF, ±10% , 100vdc, L.S. 0.400"	0.0009	0.41

APPENDIX D

Angstor Product Process Flow and Control Plan

Process	Variables	Control
Margin	Lane Spacing Margin Spacing	Individual Readings (each roll) Individual Readings (each roll)
Wind	Floater Extension	Individual Readings (each belt) Individual Readings (each belt)
Load	None	None
Spray	Stick Width	X-bar and R Control Chart
Stick Calibration	Capacitance Dissipation Factor Voltage	AC and DC voltage is applied to each stick and then each stick is 100 % measured for Capacitance and Dissipation Factor
Saw	Capacitance Cut Height	X-bar and R Control Chart X-bar and R Control Chart
Block Test	Capacitance Dissipation Factor Voltage Insulation Resistance	100 % Capacitance, Dissipation Factor, Voltage and Insulation Resistance test
Tape (premarked)	Tape Quality	Visual
Lead Attach	Lead Strength, Lead Placement	Median Control Chart
Wax	None	None
Final Test	Capacitance Dissipation Factor Voltage Insulation Resistance	100 % Capacitance, Dissipation Factor, Voltage and Insulation Resistance test
First QC Inspection	Capacitance Dissipation Factor Voltage Insulation Resistance Physical Dimensions	AQL sampling of Capacitance, Dissipation Factor, Voltage, Insulation Resistance and Physical dimensions
Lead Cut and bulk/tubing/reeling	Lead dimensions	Go/No-go gauges and AQL sampling
Final QC Inspection	Lead Dimensions and bulk/tubing/reeling quality	Visual and AQL sampling
Ship/Stock		

Capstick Product Process Flow and Control Plan

Process	Variables	Control
Margin	Lane Spacing Margin Spacing	Individual Readings (each roll) Individual Readings (each roll)
Wind	Floater Extension	Individual Readings (each belt) Individual Readings (each belt)
Load	None	None
Spray	Stick Width	X-bar and R Control Chart
Stick Calibration	Capacitance Dissipation Factor Voltage	AC and DC voltage is applied to each stick and then each stick is 100 % measured for Capacitance and Dissipation Factor
Saw	Capacitance Cut Height	X-bar and R Control Chart X-bar and R Control Chart
Block Test	Capacitance Dissipation Factor Voltage Insulation Resistance	100 % Capacitance, Dissipation Factor, Voltage and Insulation Resistance test
Tape	Tape Quality	Visual
Wax	None	None
Lead Frame Attach	Lead Strength	Median Control Chart
Conformal Coat	Coating Quality	Visual
Marking	Marking Quality	Visual
Final Test	Capacitance Dissipation Factor Voltage Insulation Resistance	100 % Capacitance, Dissipation Factor, Voltage and Insulation Resistance test
First QC Inspection	Capacitance Dissipation Factor Voltage Insulation Resistance Physical Dimensions	AQL sampling of Capacitance, Dissipation Factor, Voltage, Insulation Resistance and Physical dimensions
Lead Cut & Form and tubing/reeling	Lead dimensions	Go/No-go gauge and AQL sampling on lead forming
Final QC Inspection	Lead Dimensions and tubing/reeling quality	Visual and AQL sampling on tubing/reeling
Ship/Stock		

Surfilm Product Process Flow and Control Plan

Process	Variables	Control
Margin	Lane Spacing Margin Spacing	Individual Readings (each roll) Individual Readings (each roll)
Wind	Floater Extension	Individual Readings (each belt) Individual Readings (each belt)
Load	None	None
Spray	Stick Width	X-bar and R Control Chart
Stick Calibration	Capacitance Dissipation Factor Voltage	AC and DC voltage is applied to each stick and then each stick is 100 % measured for Capacitance and Dissipation Factor
Saw	Capacitance Cut Height	X-bar and R Control Chart X-bar and R Control Chart
Block Test	Capacitance Dissipation Factor Voltage Insulation Resistance	100 % Capacitance, Dissipation Factor, Voltage and Insulation Resistance test
Impregnation	None	None
Final Test	Capacitance Dissipation Factor Voltage Insulation Resistance	100 % Capacitance, Dissipation Factor, Voltage and Insulation Resistance test
QC Inspection	Capacitance Dissipation Factor Voltage Insulation Resistance Physical Dimensions	AQL sampling of Capacitance, Dissipation Factor, Voltage, Insulation Resistance and Physical dimensions
Ship/Stock		

Appendix E

RoHS-5

Standard Product

Angstor, Capstick and Surfilm (RA, RB, RS, CB, CS, ST3 and ST4):

ITW Paktron is in compliance with Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the use of certain hazardous substances in electrical and electronic equipment for all articles, products, materials and parts thereof being supplied to Paktron's target Sales markets on a RoHS-5 compliance level and that the information submitted is true and accurate. RoHS-5 means that the content of five RoHS banned materials (Hg, CrVI, Cd, PBB and PBDE) are under the industry-defined limits stated below. RoHS-5 compliant products have Pb in the termination (secondary interconnect: i.e. terminal leads and lead frames) and match conventional SnPb board assembly requirements for those markets exercising Pb solder exemptions. Exempt categories under RoHS currently include the Servers, Storage, Network and Telecom equipment, Medical, Aerospace, Military and Automotive markets. While the terminations contain Pb, the total unit Pb content of Paktron's products is under the industry-defined limits stated below.

RoHS-6

Standard Product

Quencharc and Surfilm (QA, QB, QC, QD, QE, QH, QRL, QV, ST2824 and ST3827):

ITW Paktron is in compliance with Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the use of certain hazardous substances in electrical and electronic equipment for all articles, products, materials and parts thereof being supplied by Paktron on a full RoHS-6 compliance level and that the information submitted is true and accurate. These Paktron products do not contain any of the six RoHS banned chemicals, compounds or elements listed, in levels exceeding the industry-defined limits stated below.

Special Lead-Free Product

Angstor, Capstick and Surfilm (RA, RB, RS, CB, CS, ST3 and ST4):

ITW Paktron is in compliance with Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the use of certain hazardous substances in electrical and electronic equipment for all articles, products, materials and parts thereof being supplied by Paktron on a full RoHS-6 compliance level, on a specialized part number basis (consisting of an added suffix of –F?; with the ? assigned at time of order/quote), and that the information submitted is true and accurate. Paktron's special lead-free products do not contain any of the six RoHS banned chemicals, compounds or elements listed, in levels exceeding the industry-defined limits stated below and also do not contain Pb in the terminations.

The maximum reflow temperature for surface mount product remains at 220°C while the maximum wave solder temperature for thru-hole product is 260°C.

Chemical, Compound, or Element Content:

Maximum limit of 0.1% by weight (0.1w percent or 1000ppm):

- Polybrominated Diphenyl Ethers (PBDE); $C_{12}H_{(10-n)}Br_nO$
  Pentabromodiphenyl ether (PentaBDE) – CAS number 32534-81-9; $C_{12}H_5Br_5O$;
  Octabromodiphenyl ether (OctaBDE) - CAS number 32536-52-0; $C_{12}H_2Br_8O$
  Decabromodiphenyl ether (DecaBDE) – CAS number 1163-19-5; $C_{12}Br_{10}O$
- Polybrominated Biphenyls (PBB)
  Decabromobiphenyl (DeBBB) – CAS number 13654-09-6; $C_{12}H_{(10-x-y)}Br_{x+y}$
- Mercury – CAS number 7439-97-6; Hg
- Hexavalent Chromium – CAS number 18540-29-9; CrVI
- Lead – CAS number 7439-92-1; Pb

Maximum limit of 0.01% by weight (0.01w percent or 100ppm):

- Cadmium – CAS number 7440-43-9; Cd

Appendix F

SOLDERING GUIDELINES

Capstick® & Surfilm® Capacitors • Type CB, CS and ST

General

The Capstick and Surfilm capacitors Type CB, CS and ST use PET as the film dielectric and have been thermally stabilized to withstand reflow soldering temperatures for a maximum of 220°C for 30 seconds, with 1.5 minutes of allowable time at temperatures above 183°C.

Dielectric Film		
Type	Name	Code
CB	polyethylene terephthalate	PET
CS	polyethylene terephthalate	PET
ST	polyethylene terephthalate	PET

To prevent excessive changes to both the electrical and mechanical characteristics, Paktron recommends that the following soldering guidelines be observed when processing Capstick and Surfilm capacitors.

Pre-Conditioning

In case of high humidity storage and short cycle reflow soldering profiles, it is recommended that the capacitors be pre-conditioned in an 85°C oven for a minimum of 12 hours prior to reflow soldering to minimize any effects caused by the rapid vaporization of the moisture.

CAUTION

This bag contains

MOISTURE-SENSITIVE DEVICES

1. Shelf life in sealed bag: 12 months @ < 40°C and < 90% relative humidity (RH).
2. Peak package body temperature: 220 °C
3. After this bag is opened, devices that will be subjected to reflow solder or equivalent high temperature processing must be:
   a) Mounted within 72 hours at factory conditions of ≤ 30°C / 60% RH, or
   b) Stored at ≤ 10% RH.
4. Devices require baking, before mounting, if:
   a) 3a or 3b are not met, or
   b) If applicable, a Humidity Indicator Card reads >10% RH, when read at 23°C ±5°C.
5. If required, devices may be baked for:
   a) 48 hours @ 50°C +5°C/-0°C and <5% RH in reels/tubes or
   b) 12 hours @ 85°C +0°C/-5°C and <5% RH in bulk.

Bag Seal Date: ____________

(if blank, see barcode label)

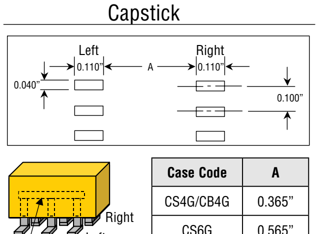
Level 4

ITW Paktron
1205 McConville Rd.
Lynchburg, VA 24502

MLP Mounting Pad Layout

Typical Recommended

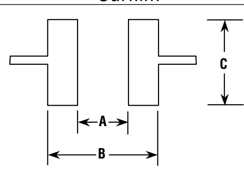
Capstick



Case Code	A
CS4G/CB4G	0.365"
CS6G	0.565"

Note: All left side capacitor leads are joined in common internal to the capacitor and all right side capacitor leads are also joined in common internal to the capacitor.

Surfilm



Recommended Pad Sizes (inches)			
Case Code	A	B	C
ST2824/ST3	0.210	0.365	0.275
ST3827/ST4	0.310	0.465	0.305

Solder Paste Thickness

Depending upon pad geometry, the recommended solder paste thickness is .006" (6 mils) to .010" (10 mils). For optimum performance, 8 mils to 10 mils should be used. In the case where small pitch components do not allow extra paste thickness, use of a "step screen" should be considered.

Board Attachment

Due to their low mass, it is recommended that for optimum soldering results, Surfilm capacitors be spot glued to the substrate.

Board Cleaning

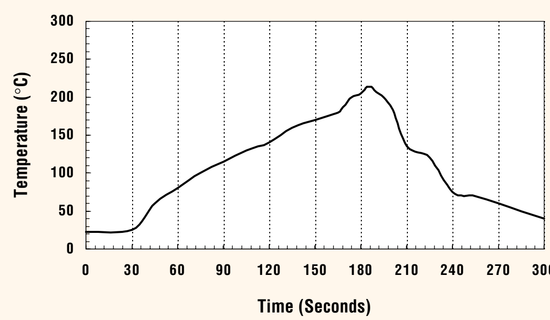
When cleaning the boards, avoid the use of alcohol based solvents. These may cause a temporary drop in the insulation resistance of the capacitor. The manufacturer's safety data sheet should also be studied carefully before using any solvent.

Maximum Solder Reflow Temperatures

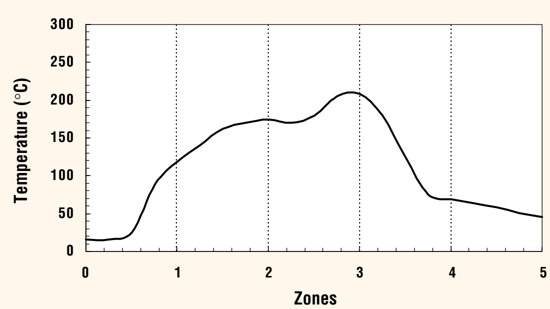
Do not exceed the following temperatures:

Manufacturing Solder Method	Maximum Temperature		
	CB	CS	ST
Conductive Reflow	220°C	220°C	220°C
Convection Reflow	220°C	220°C	220°C
IR Reflow	220°C	220°C	220°C
Vapor Phase Reflow	NA	NA	220°C
Soldering Iron	220°C	220°C	220°C
Wave Solder	NA	NA	NA
Wave Solder (thru-hole)	260°C	260°C	NA

Convection Reflow Profile (Typical)



IR Reflow Profile (Typical)



SOLDERING GUIDELINES

Capstick® & Surfilm® Capacitors • Type CB, CS and ST

Hand Soldering Surfilm Capacitors

The following hand soldering method has proven to be satisfactory for soldering small quantities of Surfilm capacitors to printed circuit pads.

Materials and Equipment:

a. Use a soldering iron that will control the iron tip temperature to 220°C maximum. The Weller EC 2002C Soldering station and the EC1201P Iron will provide the temperature control needed

b. To reduce the heat exposure time, use a low temperature solder alloy with a low residue solder flux. A 0.030" diameter X32B cored solder with an alloy of 43% Tin, 43% Lead, and 14% Bismuth has a soldering range of 143°C to 163°C (289°F to 325°F.

c. For ease of handling, prevention of contamination and personal injury, a pair of small tweezers should be employed to position the units for hand soldering.

Procedure:

1. Flow a thin bead of solder to one printed circuit pattern.

2. Center the capacitor to be soldered on the printed circuit electrode and place a small quantity of solder on the iron tip. Place the iron point at the junction of the capacitor electrode and printed circuit electrode and reflow the solder while applying a force to the top surface of the capacitor so that it will seat flush against the printed circuit pattern.

3. Clean the iron tip and apply the tip and solder to the opposite printed circuit and capacitor electrode junction until the solder wets the full length of the PC electrode and capacitor electrode. Do not apply a force to the top of the capacitor when soldering the second electrode.

4. Examine the first side soldered and repeat step 3 on the first side if required. The first solder application of step 2 is to mechanically position the capacitor on the board and hold it in place so that both hands are free to apply both the solder and iron tip to the second electrode. A full solder wetting may not be accomplished in step 2.

Important Points In MLP Soldering

1. Reflow Temperature: The maximum reflow solder temperature for capacitors made with PET based film dielectric is specified at 220°C. Type CB, CS and ST are made with low shrinkage PET dielectric film that has been thermally stabilized to withstand reflow soldering temperatures for a maximum of 220°C for 30 seconds, with 1.5 minutes of allowable time at temperatures above 183°C. Typical reflow temperature profiles are shown on the proceeding page. Exceeding the recommended maximum temperature is one of the leading causes of soldering problems. On Type ST Product, excessive reflow temperatures can cause product swelling and shrinkage/ curling of the white coverplates, which can lift the terminations out of the solder paste and create a "drawbridge" condition that prevents complete soldering.

2. Solder Paste Thickness: While reliable solder joints have been formed using paste thicknesses as low as 4 mils, for optimum performance, 8 mils to 10 mils should be used.

3. Mounting Pad Sizes: The recommended pad size geometry is shown on the proceeding page.

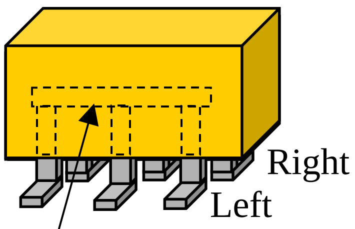
4. Board Attachment: Due to the low mass of the Type ST product, it is recommended that the chips be spot glued to the substrate for optimum soldering results.

5. Storage Conditions and Floor Life: The Capstick and Surfilm component reel packaging from the factory is "dry pack." Dry packing involves sealing the reel of product with a desiccant inside a moisture-barrier bag. This type of packaging provides moisture protection for 12 months @ <40°C / <90% RH. The Floor Life or "out-of-bag" exposure time is categorized according to the "JEDEC Moisture-Sensitivity Level" specification. The Capstick and Surfilm products meet "Level 4" which allows for "out-of-bag" exposure time @ 30°C / 60% RH of 3 days (72 hours).

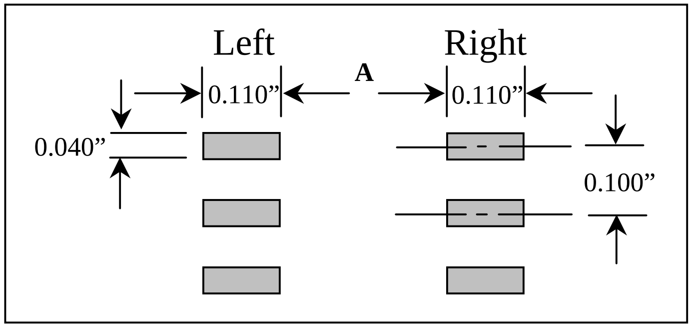
6. In the case of open exposure to high humidity storage, it is recommended that the capacitors be pre-conditioned prior to reflow soldering to minimize any effects caused by the rapid vaporization of the moisture. The capacitors can be pre-conditioned either while still in the reels and tubes @ 50°C for 48 hours or in bulk/loose @ 85°C for 12 hours at <5% RH.

Capstick Mounting Pad Layout

Typical Recommended



Note: All left side capacitor leads are joined in common internal to the capacitor and all right side capacitor leads are also joined in common internal to the capacitor.



Part Number	Number of Leads per Side	A
474K500CS6	4	0.565”
105K500CS6	8	0.565”
474K400CS6	3	0.565”
105K400CS6	7	0.565”
205K100CS4, 205K100CB4	3	0.365”
405K100CS4, 405K100CB4	3	0.365”
475K100CS4, 475K100CB4	3	0.365”
106K100CS4, 106K100CB4	7	0.365”
106K050CS4	5	0.365”
206K050CS4	9	0.365”

Appendix G

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Lynchburg, VA 24502
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FAX: 434-239-4730
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Web site: http://www.paktron.com

TECHNICAL BULLETIN 3.01

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Requirement for Robust Capacitors in High Density Power Converters

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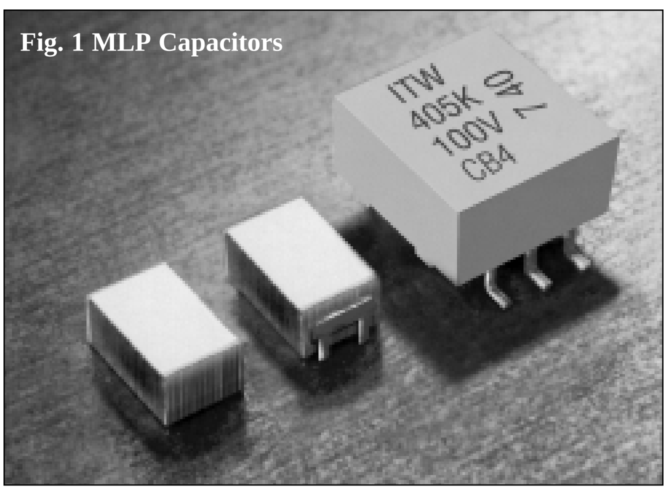
ABSTRACT

Power supply designers are faced with complex component size and part shape issues in order to minimize circuit board land area and maximize cubic space efficiency. Packing density and logical layout of the topology is often made difficult because of the mechanical and electrical shortcomings of the components. Chip capacitors are perhaps the most fragile components in the power system, being easily damaged by external physical events. Capacitor damage often occurs from process events such as pick & place, part soldering, temperature shock, and circuit board flexing during circuit board assembly. Less obvious reasons for damaged capacitors are location of chip capacitors near board edges, proximity to large heat sinks, pad size and solder fillet mass. Large chip capacitors are very fragile to mechanical shock of any kind, so it is often necessary to use multiple small units or employ special lead frame chip carriers to avoid cracking. Field problems related to chip component fragility cause converter designers to add cost in terms of component safety margin allowance and special handling and housing for the chip components on the board.

Multilayer Polymer (MLP) chip capacitors (see Fig. 1), based upon the newest low shrinkage PET polymer dielectric, offer a physical strength and mechanical flexibility that avoids cracking failures on the circuit board. Their stability under voltage and current loads provides a quality alternative to MLC capacitors in high current power conditioning circuits.

Fig. 1 MLP Capacitors



CONVERTER MANUFACTURER ISSUES

High-density power converter manufacturers have learned about capacitor component failure mechanisms through costly yield losses in the factory. Even after the power converter is in the field, once under application stress, additional component related thermo-mechanical and electrical weaknesses must be taken into account. Temperature cycling in use can cause cracking of the chip capacitor due to thermal coefficient of expansion difference between the component and circuit board material. The use of hard-set thermally conductive potting compounds and super thin circuit boards has exasperated these issues.

High in-rush current can cause a chip to break if its piezoelectric property is poor or if the dv/dt rating of the part is inadequate for spike currents on the voltage bus. Since all dielectric systems are not perfectly stable over voltage, temperature and frequency changes, worst case conditions must be planned for. At low temperature, some popular chip capacitors have very high ESR (higher by several orders of magnitude) compared to room temperature specifications. Cold start problems can result in cracked and shorted capacitors. At high frequency, the dissipation factor of all dielectrics rises, resulting in increasing ESR that limits attenuation property and can cause heat losses. Increasing AC ripple current on the capacitor causes certain dielectrics to increase in ESR to potentially run away explosive condition. Even simple DC bias on popular MLC dielectrics causes significant capacitance drop that can reduce the ripple current and load handling capability of the component. Finally, age and time have effects (normally worsening) on the capacitors that can become significant in a few short weeks. The new demands on DATACOM producers to match the 10 to 20 year life of the TELECOM producers with 100% up-time products changes component selection criteria. It must be remembered a 2000 hour product means only 83.3 days. The extrapolation to 10 years life is a far reach for most capacitor systems that are subject to electrical degradation with time.

In high frequency switching power converters, the input and output filtering function is handled by large discrete capacitors, usually configured in multiples (banks) of parallel units to achieve power handling and ripple current control. In PWM and resonant control DC-to-DC converters, the reactive input filter section requirements have usually been underestimated due to the reflected, harmonic RFI created internally, and from externally generated pulse events appearing on the system bus. Many DC-to-DC converters are under-filtered when it comes to RFI control and must be decoupled externally. Because the input filter section sees a moderate to low series current, normally one or two amps at 48 volts, a small valued capacitor can be used on the input, provided the dissipation factor is low enough to efficiently sink the ripple current, and the high frequency impedance is low enough to bypass reflected RFI. These capacitors can be either X7R ceramic or MLP film capacitors. Both types are built on a "stacked" layer construction that features very low impedance and ESR extending well beyond the switching frequency of high-density converters. Developments to provide higher capacitance values in small package sizes have now led to the use of these low ESR capacitors in output filters where the load currents are at least ten times higher than on the higher voltage input bus. The selection of an electrostatic capacitor (ceramic or film) can improve the reliability of the power system to a level where the tantalum electrolytic capacitors typically used can either be reduced in number or eliminated from the output filter. Tantalum capacitors can have very high dissipation factor, which can lead to self-heating and failure in high ripple current applications such as with TELECOM boards and CPUs.

The current handling aspect of electrostatic capacitors is fundamental to their reliability in the power train. On the input side, the in-rush current ratings are important due to the input voltage level and high-energy pulses carried on the bus. The capacitor's instantaneous current handling capability has a direct relationship on the dv/dt rating (or dv/dt rating per individual layer in the stack), in combination with the capacitance value (or number of parallel stacks). These dv/dt ratings are not readily available in product literature and can vary greatly over temperature and frequency. A working knowledge of in-rush current effects under typical converter usage parameters is paramount in understanding the reliability of the ceramic and film capacitors presently used on the input filter section. Since the input section is normally 48 volts or higher, any misapplication can produce a high-energy failure, resulting in a "hard short". The output filter section typically features high ripple currents at low bus voltage. The ripple current ratings of the capacitors vary widely depending upon the component temperature rise allowed, but are directly influenced by the high frequency ESR and ESL of the part (or bank of parts). Knowledge of the high frequency dissipation factor levels of ceramic, film and tantalum capacitors and how these relate to ripple current handling allows the design engineer to better determine which capacitor system is most suitable in the application (see Fig. 2).

A short circuit within parallel mounted capacitors on a power train most often exhibits a disastrous failure mode (see Fig. 3). This is true both on the input, in the series resonant tank and on the output filter of converters. Popular electrostatic capacitors featuring high capacitance values are either multilayer ceramic or multilayer polymer. While also popular, electrolytic capacitors such as tantalum capacitors have relatively high dissipation factor and are limited in operating fre-

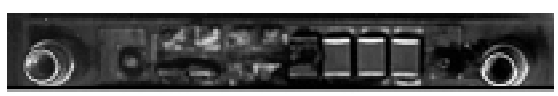


Fig. 3 Ceramic Capacitor Short Circuit Failure

Fig. 2 **Data on Typical Capacitor Types**

	Selected Value	DCV	Dissipation Factor (1KHz)	Dissipation Factor (100KHz)	ESR @ 25°C (100KHz)	Ripple Current (100KHz)
Aluminum	1000µf	6	10.0%	15.70%	0.025	1.0
Tantalum	680µf	6	6.0%	9.80%	0.023	3.0
OS-CON	330µf	6	6.0%	4.10%	0.020	3.5
Ceramic - X7R	10µf	100	2.5%	0.94%	0.015	6.0
MLP-PET	10µf	100	1.0%	0.69%	0.003	14.1
			Spec.	Actual	Spec.	

quency. Tantalum capacitors are also subject to shorting especially at elevated voltage and high di/dt conditions. For these and other reasons next generation capacitor technologies such as Paktron's MLP (Multilayer Polymer) capacitors are showing increased use as output filter capacitors where the energy levels are high and low ESR is required above 100 kilohertz.

CAPACITOR TECHNOLOGIES

A. Tantalum Capacitors

Tantalum capacitors are constructed with a very porous anode made with tantalum powder (see Fig. 4). This powder is pressed into a pellet form with a tantalum wire inserted. The pellet is sintered to allow for contact growth between the individual particles. This results in a porous structure, which electrically connects all the tantalum particles to one another as well as to the tantalum wire. The dielectric in a tantalum capacitor is formed on the exposed surfaces of the tantalum through electro-chemical treatment. The resulting film layer (dielectric) is extremely thin and the total surface area throughout the porous structure is extremely high allowing for the production of very high capacitance values.

Makers of tantalum capacitors are under pressure to reduce the ESR of the parts for extended use at high frequency, and to be more reliable on high current DC bus. Several major developments are under way to replace the manganese dioxide cathode system with a conductive polymer electrolytic cathode. Difficulties and schedule delays with these efforts have led to parallel developments to extend the capacitance values of the current manganese dioxide based products in order to reduce the ESR of the capacitors. The effort to reduce the ESR by simply increasing capacitance value has driven producers to package multiple anodes in one molded device (see Fig. 5). Unfortunately, the denser anodes tend to cause the dissipation factor to increase and the adoption of multiple anodes runs contrary to quality and reliability of design principles.

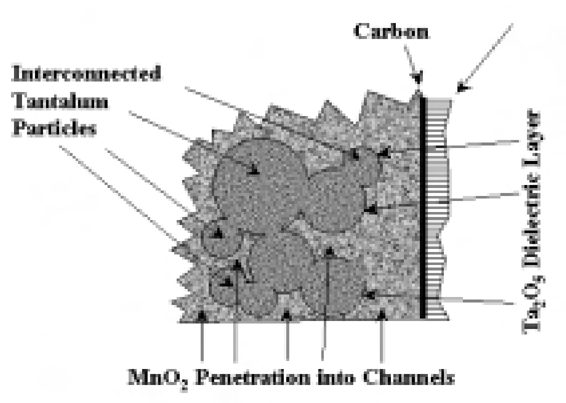


Figure 4 Tantalum Capacitor Construction

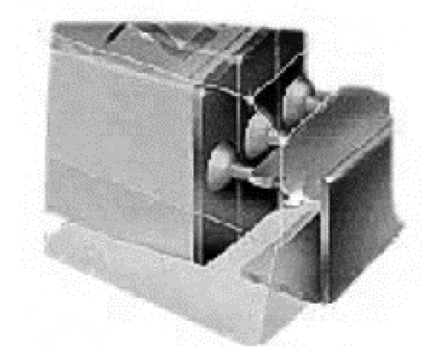


Fig. 5 Example of "Ganged" Tantalum Capacitor.

B. Multilayer Ceramic Capacitors

The typical ceramic capacitor is multilayer ceramic (MLC). This type of capacitor is a monolithic block composed of ceramic material containing two sets of offset interleaved electrodes that are exposed on opposite edges of the laminated structure (see Fig. 6). After laminating, this structure is fired at high temperature to produce a monolithic block. After firing, conductive material is applied to the opposite ends in order to make contact to the exposed electrodes. This conductive termination material typically consists of a nickel barrier layer and a tinned coating to facilitate soldering.

The multiple layers and high dielectric constant ceramic allows for the production of relatively high capacitance values per unit size. These types of capacitors are easily surface mountable and have found wide acceptance in signal level applications. Complications occur when trying to use MLC capacitors in applications requiring both "high" capacitance and "high" voltage at the same time which many times results in "cracked" layers (see Fig. 7). In contrast to MLP capacitors with its thousands of stacked layers, MLC capacitors consist of anywhere from only 20 to several hundred layers (in multi stack designs).

In the input filter section, the dv/dt or in-rush current capability of the device should always be a primary consideration.

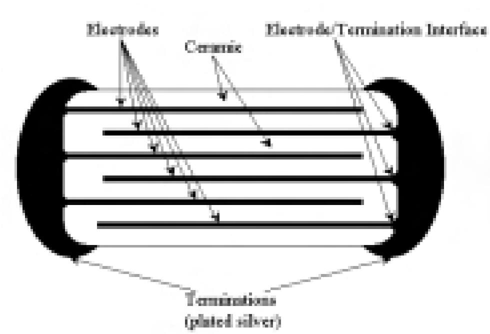


Fig. 6 Ceramic Capacitor Cross Section

Fig. 7 Ceramic Capacitor "Cracking"

Current in-rush is usually a problem at system startup. Applying 48 volts with a high di/dt can cause an instantaneous failure with certain types of capacitor. It is widely known that ceramic capacitors can fail in the short circuit mode while MLP capacitors will remain in an operational state after a "clearing" event.

In recent years, ceramic capacitor manufacturers have seen an accelerated escalation of the price of palladium metal to levels exceeding the price of gold. Palladium is a very stable, reasonably ductile, and non oxidizing noble metal which was found in virtually all multilayer ceramic (MLC) capacitors' electrode and conductive termination systems. The MLC industry is actively seeking to replace the precious metal palladium (and palladium/silver alloy) with nickel or copper base metals. This provides an opportunity for cost abatement but the simple replacement of the metal has not proven to be easy. In fact, this development has been an ongoing project within the ceramic capacitor industry for decades. It has been found that, no matter how innovative the engineering; chip capacitors made with base metal electrodes tend to be more fragile and less stable than their noble metal counterparts are (see Fig. 8). It should be noted in this magnified view that the electrode plates are highly disassociated (fragmented). While a certain degree of "lacy" electrodes is desirable (for a more monolithic block), excessive discontinuity will lead to reduced pulse handling, increased ESR and the potential for "hot spots" that significantly decrease reliability.

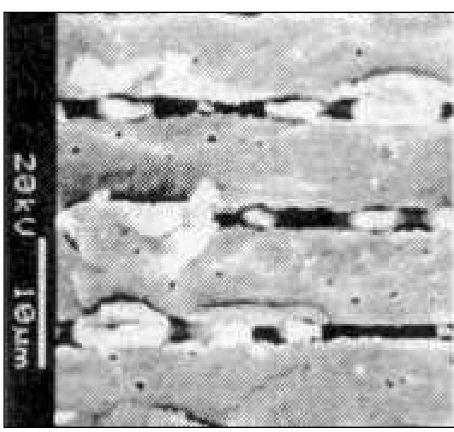


Fig. 8 Example of Ceramic Capacitor with Base Metal Electrodes

C. Metallized Film Capacitors

Metallized film capacitors consist of thin film layers of polymer based material upon which a metal has been vapor deposited to act as electrode plates. Many designers who use metallized film capacitors do not realize that although all film capacitors use the same base capacitor materials, metallized film capacitors are produced by two significantly different base construction technologies that will behave radically different in their applications. One of these technologies is a "wound" construction and the other "stacked" (see Fig 9). "Wound" technology takes two offset lengths of film and rolls an individual cylindrical capacitor. Should the form factor require a modification, the cylinder is flattened and an oval capacitor formed. "Stacked" capacitor technology takes the same two offset lengths of film (or more) and winds the layers together on a large wheel to form a mother capacitor. The mother capacitor has its layers laminated together and is sawed into individual capacitors.

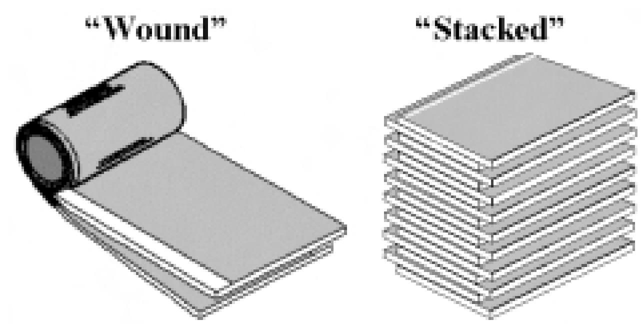


Fig. 9 Metallized Film Construction

"Wound" technology has produced high quality, mass producible product for decades. Unfortunately, it does have several limitations in its use in high-density power converters. The Interleaf“ Technology construction that is used to produce MLP capacitors is based on "stacked" construction (see Fig. 10).

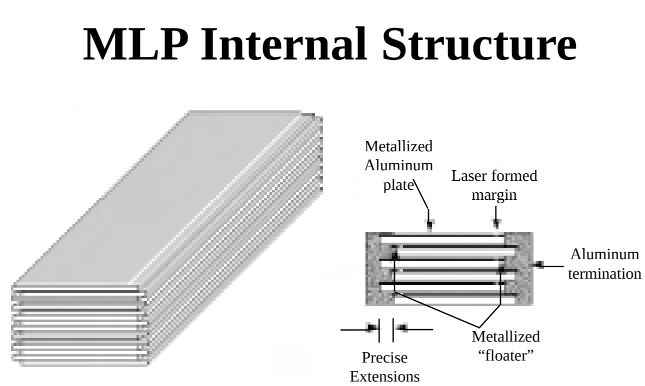


Fig. 10 MLP Internal Structure

The advantages in "stacked" vs "wound" are significant and include such things as lower inductance, lower dissipation factor, lower ESR, higher current handling, better stability, improved volumetric efficiency and being far more conducive to mass production (see Figs. 11 and 12).

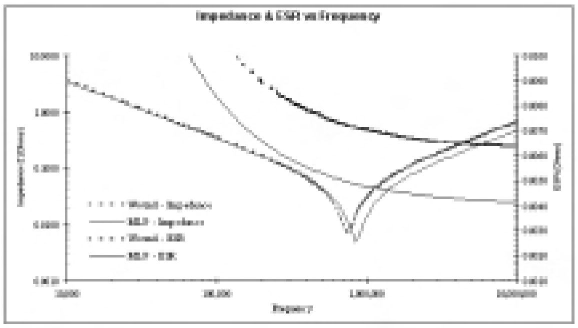


Fig. 11 Wound vs Stacked Comparison Graph

	Worst Case Sample Readings	
Parameter	**Stacked**	**Wound**
ESR @ 500KHz	5.29mΩ	7.74mΩ
Resonance Freq.	853KHz	743KHz
Eqv. L	3.1nH	6.9nH
Eqv. R	4.86mΩ	7.35mΩ

Typical reading taken on 4.7mfd 100vdc units

Fig. 12 Wound vs Stacked Comparison Table

The MLP style capacitor employs metallized electrode construction. These electrode plates are composed of 100-300 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 (Rt) for the capacitor (typically under 10 milliohms). For example, a capacitor could have 1.0 ohms per layer of DC resistance, but because there can easily be 2,000 paralleled stacks within the capacitor, the total resistance of the electrode plates would only be 5.0 milliohms (see Fig. 13).

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. Depending upon the capacitor’s rated voltage, the dielectric thickness of each of these layers can range from 0.6 micron to 8.0 microns, with a micron being approximately 1/10,000 the

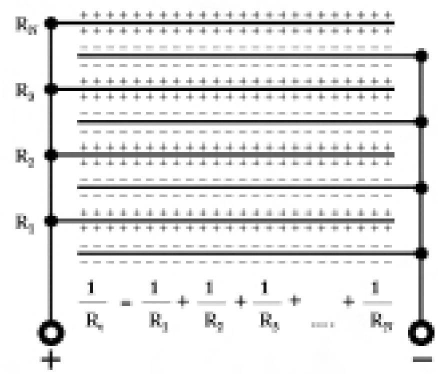


Fig. 13 MLP Capacitor Electrode Resistance

thickness of a human hair (1 micron = 0.000040"). Stacking 2,000 layers of 1 micron thick dielectric results in a basic capacitor block thickness of only 2.03mm (0.080").

Metallized film capacitor manufacturers have been under intense pressure to produce a more thermally resilient chip component, one that can withstand convection reflow soldering without damage. Some manufacturers have developed processes to thermally set the well known PET dielectric at the molecular level and produce chip capacitors suitable for reflow use up to 220°C. However, most film chip producers lack this technology and have rushed into developments using higher temperature film dielectrics such as PEN and PPS. The objective of producing a higher temperature film chip capacitors using these more exotic films has been achieved but performance and quality problems have also quickly surfaced. Field failures have shown that neither PEN nor PPS have the graceful aging characteristic of PET dielectric and can be subject to short circuit failure under certain conditions. Base film manufacturers are continuing to work on improving these and other high temperature films and someday hope to have a viable solution.

MUTUALLY EXCLUSIVE DEVELOPMENTS

The market pressure for reduced cost and size has driven capacitor design developments that are at odds with the Power Converter Industry’s desire for more robust, stable and easy to handle components. The first choice of capacitor makers to increase capacitance density is to increase the dielectric constant. Increasing the "K" causes the dielectric to be less stable and more sensitive to environmental changes. The second choice to increase capacitance (and hopefully current handling) is to thin down the dielectric, bringing the electrode plates closer together. This simple effort tends to drive the voltage withstanding per thickness to higher stress levels, which in itself, lowers the inherent safety margin of the capacitor design. Dielectric thickness reduction tends to make the components physically harder to build, a situation that seldom leads to increased quality. A third choice is to abandon known materials and processes in favor of newer materials such as base metal electrodes, polymerized electrolytes and new polymer thin films. These efforts are admirable but must be fully developed and field tested to understand the long term reliability of the new systems prior to commercial release.

STUDY OF CAPACITOR ROBUSTNESS

When determining the robustness of a capacitor it is necessary to examine both its electrical and mechanical stability.

A. Board Flexure Testing

Flexure or printed wiring board (PWB) bending is a significant source of stress that can lead to component failure. Ceramic capacitors are inherently brittle and can exhibit catastrophic failure if cracked during PWB bending if the crack propagates across opposing electrodes and there is sufficient energy present in the power supply. MLP capacitors are made with polymer films, which are not brittle under normal conditions and are more forgiving when physically stressed. The most common test procedures for this type of robustness follow EIAJ specification RC3402 where a capacitor is reflow soldered to pads on a test PWB. The assembly is mounted component face down, supported on the PWB ends and bending stress is applied to the backside of the assembly with a ram directly behind the component under test. The basic setup is shown in Figure 14. Capacitance shift is used to detect failure under test conditions but this may not detect cracking of ceramic capacitors. The standard also uses a 1mm deflection as an acceptance level for no failures. A test PWB with 1mm of deflection is also shown in Fig. 14. A maximum deflection of only 1mm is difficult to achieve at every step of PWB assembly and final product manufacturing to eliminate flexure cracking of ceramic capacitors. Fig 15 shows some typical results of flexure testing on ceramic and MLP capacitors.

Board Flexure Comparision between Surface Mount Multi-layer Ceramic and Film Capacitors

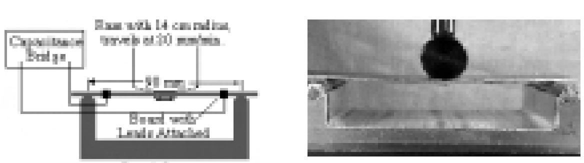


Fig. 14 Board Flexure

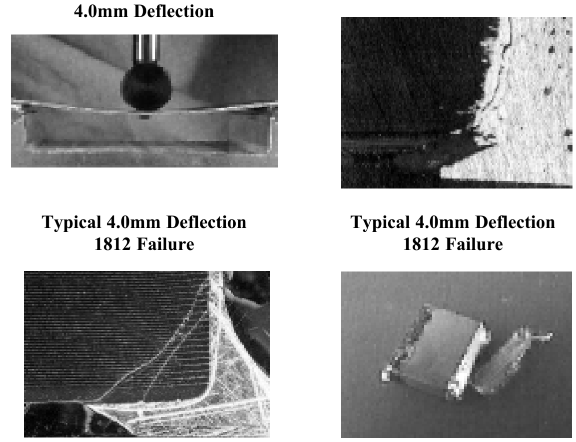


Fig. 15 Visual Results of "Board Flexure"

Flexure testing has found that while all 1812 ceramic chip capacitors tested in this particular test set failed between 3.0 and 4.0mm of deflection, MLP chip capacitors flexed at 7.0mm and subjected to 500 hours of accelerated life testing showed no failures or degradation (See Fig. 16). Throughout the testing, it was evident that MLP capacitors did not exhibit

Post Board Flexure

MLP Life Test Data Summary after 500 Hours at 125˚C and 100V DC

Part Number	Parameter	Limit/Actual Average
224K100ST1812	% Delta Cap	5.00/2.1
	% DF	1.00/0.55
	IR (Meg Ohm)	1000/100,000
105K100ST2824	% Delta Cap	5.00/1.75
	% DF	1.00/0.51
	IR (Meg Ohm)	1000/70,000
225K100ST3827	% Delta Cap	5.00/1.91
	% DF	1.00/0.54
	IR (Meg Ohm)	454/15,000
105K100ST3	% Delta Cap	5.00/3.09
	% DF	1.00/0.55
	IR (Meg Ohm)	1000/100,000
405K100CB4	% Delta Cap	5.00/2.28
	% DF	1.00/0.54
	IR (Meg Ohm)	250/12,000

Fig. 16 MLP "Board Flexure" Robustness

failure or degradation when tested at or beyond deflection values that cracked ceramic capacitors of similar size and values. The testing also indicated that the use of gull wing and J lead surface mount capacitors of either type survived test PWB deflection without degradation or failure.

B. Temperature Coefficient of Expansion

Placement of chips on PWBs via reflow soldering requires that the coefficients of expansion of the various materials be close enough that the expansion stresses do not cause failures to occur. An analysis of the various CTEs shows why large chip capacitors are so prone to failure. Figure 17 shows that MLP capacitors and FR4 boards have virtually identical CTEs.

CTEs

On Typical Components and Substrates

Material	CTE (ppm/°C)
Ceramic Capacitor	9.5-11.5
Alumina	≈7
Copper	17.6
Copper Clad Invar	6-7
Filled Epoxy Resin	18-25
FR-4 PC Board	≈18
Nickel or Steel	≈15
Polyimide/Class PCB	≈12
Polyimide/Kelvar PCB	≈7
Tantalum	6.5
Tin Lead Alloys	≈27
MLP "Polymer" Capacitor	≈17

CTE - Coefficient of Thermal Expansion a.k.a. TEC

Fig. 17 Typical Coefficient of Thermal Expansions

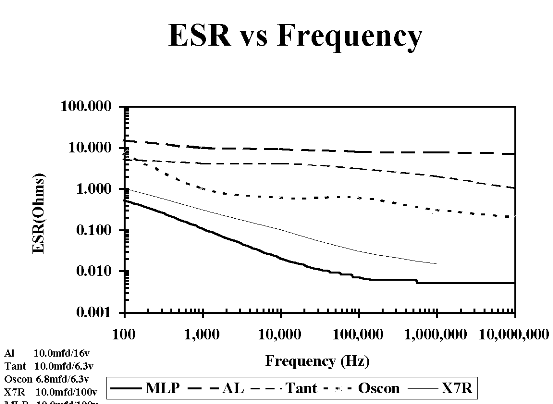


Fig. 18 ESR vs Frequency

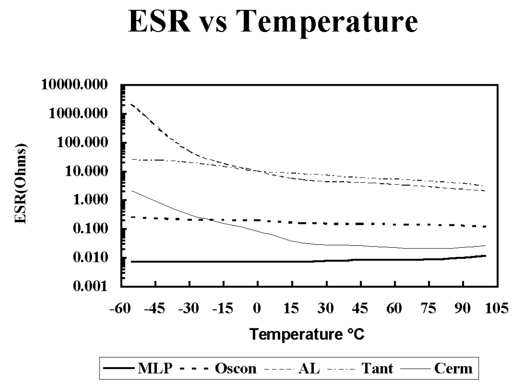


Fig. 19 ESR vs Temperature

C. ESR Stability

One of the most important attributes of a capacitor used in power circuits is its Equivalent Series Resistance (ESR). ESR determines the I2R heating losses for the capacitor, which in turn establishes the efficiency, pulse handling and indirectly the reliability of the circuit. Figures 18 and 19 show comparisons of the ESR of various dielectric systems and how they vary with temperature and frequency.

The charts in Figures 18 and 19 show that MLP capacitors, in terms of "high valued" capacitance and small package size, represent the lowest ESR valued capacitors available.

Figures 20, 21 and 22 show comparisons between ceramic and MLP capacitors for the critical parameters of dissipation factor (capacitor losses) and change of capacitance under DC bias and temperature variation.

CONCLUSION

With DATACOM applications seeking to achieve the 5x9 (99.999%) up time reliability levels required for most TELECOM applications, the choice of the proper components used in high-density power converters has become more crucial than ever. Instead of using capacitors that simply get by, critical applications require units with an established track record of both durability and reliability. The TELECOM industry learned decades ago that while the other capacitor technologies have their viable uses, in pivotal applications only metallized film capacitors have the inherent performance, stability and reliability needed. With their ultra-low ESR, outstanding power handling capabilities and small package size, MLP capacitors are positioned to see increased use in these leading edge type applications.

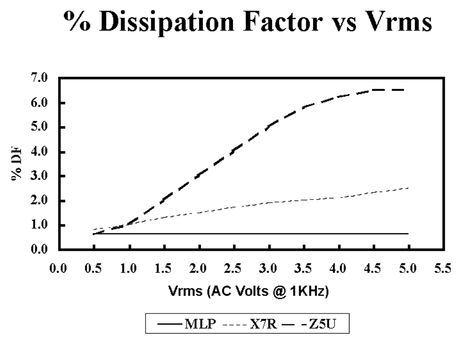


Fig. 20 % Dissipation Factor vs Vrms

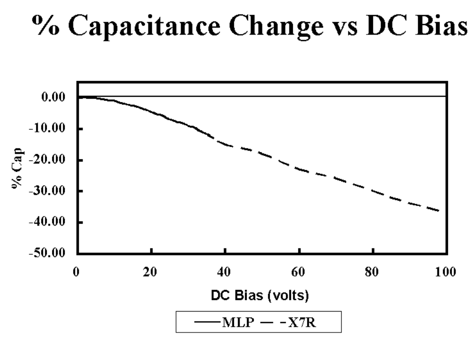


Fig. 21 % Capacitance Change vs DC Bias

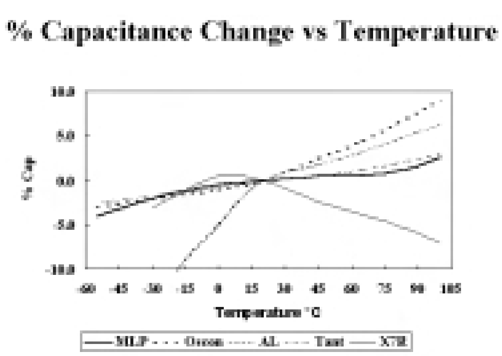


Fig. 22 % Capacitance Change vs Temperature

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