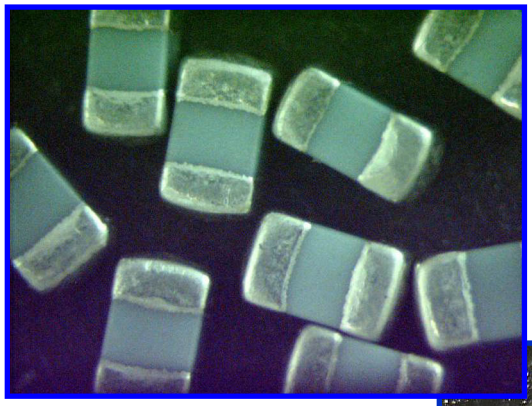

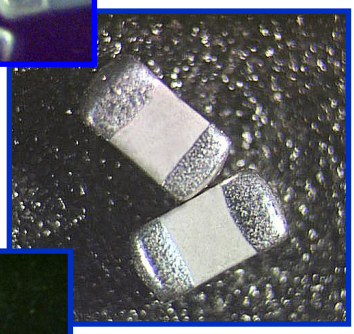

MLC Quality and Reliability Data

knowles
DLI•Novacap•Syfer•Voltronics

2777 Route 20 East
Cazenovia, New York, 13035
Phone: (315) 655-8710
Fax: (315) 655-8179
www.knowlescapacitors.com

Reliability Data

General Manufacturing Process

At each manufacturing step, defined process controls have been established. Statistical techniques are utilized to identify key parameters within processes and to reduce the variation of these parameters.

Testing is completed according to the customer's specification. Typical screening includes MIL–PRF-55681 level testing as appropriate. Capacitance, Dissipation Factor, Dielectric Withstanding Voltage, Insulation Resistance, and Visual Inspection are examined on each lot.

Multilayer Capacitor Process Control

In addition to carefully selected in-process controls, a sample of capacitors from each lot of multilayer capacitors is micro-sectioned to verify structural integrity and the absence of voids, delaminations, cracks, or other defects.

After completion of manufacturing parts may be subjected to DLI's Thermal Stress Screening to further confirm the absence of any latent defects. Finally, 100% screening for: Capacitance, Dissipation Factor, Dielectric Withstanding Voltage, Insulation Resistance and Visual defects is performed on each lot.

Reliability Testing – Equivalent Part Failure Rate, Part Failure Rate, MTBF, FITs

Growing out of the military market, DLI has retained the rigid qualification and reliability standards which are required for military contracts and expected on commercial applications. DLI routinely performs accelerated testing on products to prove their long term reliability.

The following pages contain summary Reliability Test Data for various product types of Multilayer Layer Capacitors. DLI uses MIL-PRF-55681 as a guideline testing to verify key capacitor performance characteristics.

Using the life test data presented the FR level symbol (S, R, P, M, L) and equivalent part failure rate can be determined using MIL-STD-690C. DLI performs calculations at a 90% confidence level and $\alpha = 0.10$ (consumers risk). Life testing is performed at the maximum rated voltage at the maximum rated temperature. An acceleration factor of 8:1 has been used to relate life test data obtained at 200% of rated voltage at maximum rated temperature, to rated voltage at rated temperature. This data is compiled for each product type and listed according to the time period in which the data was obtained.

Using the life test data the Part Failure Rate, λ_p, can be determined through the application of MIL-HDBK-217F. A knowledge of the end use conditions is necessary for the calculations. The Part Failure Rate, Mean Time Between Failures, and Failures in Time rates are related as shown below.

λ_p = Failures / 10^6 hours = Failures / Million hours

MTBF = 1 / λ_p = hours / Failure

FITs = λ_p * 1000 = Failures / 10^9 hours = Failures / Billion hours

Mean Time To Failure Estimation

MTTF (Mean-time-to-failure) is the basic measure of reliability for non-repairable items. It is analogous to the more familiar MTBF (Mean-to-Between-Failures) used for systems which can be repaired and placed back in service after failure occurs. Generally, MTTF is calculated as

$$MTTF = \frac{\text{Total Cumulative Hours Tested}}{\text{Total Number of Failure Experienced}}$$

However for highly reliable parts, it is not uncommon that no failures will be experienced over the period of testing. In such cases, the above formula is inappropriate. This has been the case with DLI capacitors.

It is possible, however to approximate a lower limit on the reliability of the part (in other words a figure to determine the product will last *at least as long as…)* using the following formula

$$\text{Lower Bound} = \frac{\text{Total Cumulative Hours Tested}}{-\ln(a)} \quad \text{(See note 1)}$$

where *a* is related to the confidence level for the estimate by

$$\text{Confidence} = 100\,(1 - a)\%$$

Thus for 95% confidence, $a = 0.05$

Predicted Reliability Over Time is determined using the assumption that the reliability distribution is exponential. Given this assumption, the reliability at time t=k hours is calculated as

$$\text{Reliability} = \text{EXPONETIAL}\,(-(\text{Time}/\text{MTTF}))$$

Note 1:
For reference see Meeker, William Q and Escobar Luis A (1998) Statistical Methods for Reliability Data John Wiley & Sons Publishers p 168 (ref formula 7.17)

Multi-Layer Capacitor – Reliability Test Conditions

Thermal Shock and Immersion
Capacitors are Thermal Shocked in accordance with MIL-STD-202, Method 107, condition A, with a temperature range from -55°C to +125°C.

Following Thermal Shock, the capacitors are Immersion tested in accordance with MIL-STD-202, Method 104, Test Condition B. The capacitors are cycled from a Hot Tap Water Bath at 65°C for 15 minutes to a cold bath of sodium chloride and water at a temperature of 25°C for 15 minutes.

Post Test Limits:

Insulation Resistance	± 30% of Initial Value
Capacitance change	≤ the greater of 0.5% or ± 0.5 pF of Initial Value for AH, CF, and NA materials
	≤ ± 10% of Initial Value for BL materials
Dissipation Factor	= Original Specification

Resistance to Soldering Heat
Capacitors are tested in accordance with MIL-STD-202, Method 210. Capacitors are mounted on alumina substrates using SN62 solder. The substrate is dipped (up to the bottom of the substrate) to simulate a wave solder operation. Initial and final measurements of Capacitance, Dissipation Factor, and Insulation Resistance are recorded.

Post Test Limits:

Insulation Resistance	± 30% of Initial Value
Capacitance change	≤ the greater of 0.5% or ± 0.5 pF of Initial Value for AH, CF, and NA materials
	≤ ± 10% of Initial Value for BL materials
Dissipation Factor	= Original Specification

Resistance to Moisture
Capacitors are tested in accordance with MIL-STD-202, Method 106. Capacitors are subjected to 20 continuous cycles from 90-98% Relative Humidity at 65°C to 80-98% Relative Humidity at 25°C with a 50 Vdc bias applied. Initial and final measurements of Capacitance, and Insulation Resistance are recorded.

Post Test Limits:

Insulation Resistance	± 30% of Initial Value
Capacitance change	≤ ± the greater of 0.3% or ± 0.3 pF of Initial Value for AH, CF, and NA materials ≤ ± 10% of Initial Value for BL materials

Low Voltage Humidity
Capacitors are tested in accordance with MIL-STD-202, Method 103, Condition A. Capacitors are subjected to 85% Relative Humidity at 85°C for 240 hours with a 1.5 Vdc bias applied. Initial and final measurements of Capacitance, and Insulation Resistance are recorded.

Post Test Limits:

Insulation Resistance	± 30% of Initial Value
Capacitance change	≤ the greater of 0.3% or ± 0.3 pF of Initial Value for AH, CF, and NA materials. ≤ 10% of Initial Value for BL materials

Life Testing
Capacitors are tested in accordance with MIL-STD-202, Method 108, Condition A. Capacitors are subjected to 125°C for 2000 hours with a dc bias voltage of 2 times rated voltage with a maximum surge current of 50 mA. Capacitors with a rated voltage > 500 volts are tested at 1000 volts. This data is denoted below. Initial and final measurements of Capacitance, Dissipation Factor, and Insulation Resistance are recorded.

Post Test Limits:

Insulation Resistance	± 30% of Initial Value
Capacitance change	≤ the greater of 2.0% or ± 0.5 pF of Initial Value for AH, CF, and NA materials ≤ 10% of Initial Value for BL materials

MultiLayer Capacitors – Reliability Data Summary

	Data Collection Period	Number of Lots	Number of Components Tested	Number of Component Failures	*Cumulative* Test Hours	Accelerated Test Hours	% Failure Rate	FR Equivalent Failure Rate (%/1,000 hr)	*Reliability* MTTF: 95% Confidence (hr)	Predicted Reliability t=10 Years
Life Testing - All Types										
CXXCF	*06/96 - 12/05*	141	5058	0	12,408,000	99,264,000	0%	0.01%	*33,135,162*	99.7%
CXXAH	*06/96 - 12/05*	168	6394	0	13,052,000	104,416,000	0%	0.01%	*34,854,944,*	99.7%
CXXBL	*06/96 - 12/05*	47	1927	0	4,118,000	32,944,000	0%	0.01%	*10,996,986*	99.2%
CXXUL	*06/96 – 12/05*	48	1936	0	4,224,000	33,792,000	0%	0.01%	*11,280,055*	99.2%
Low Voltage Humidity All Types	*06/96 - 12/05*	267	5396	3[1]			*0.058%*			
Resistance to Moisture All Types	*06/96 - 12/05*	352	3388	7[2]			*0.207%*			
Resistance to Solder Heat - All Types	*06/96 - 12/05*	377	3523	0			*0%*			
Thermal Shock & Immersion - All Types	*06/96 - 12/05*	373	5533	0			*0%*			

Remarks:

1. There were three part failures for Low Voltage Humidity that occurred in 1998. One failure occurred in testing on part type C11AH. This failure was attributed to a process flaw and was isolated to one manufacturing lot that was not shipped to any customers. Corrective measures have been implemented and follow-up testing confirmed the effectiveness of the action taken. Two failures occurred in Low Voltage Humidity on part type C08BL. These Failures occurred on an initial design of the product. This part type has been re-designed to eliminate this type of defect with no detrimental effects to the electrical performance of the product.
2. There were seven part failures for Resistance to Moisture testing that occurred in 2001. All seven failures occurred in testing on one lot of part type C17CF. The failure was attributed to one lot of raw material which was at the low end of a specification. Subsequent corrective measures tightened the specification and follow-up testing confirmed the effectiveness of the action taken.

MultiLayer Capacitors – Thermal Shock and Immersion

Data Collection Period	Temperature Characteristic	Number of Lots	Number of Components Tested	Number of Component Failures	Cumulative Components Tested	Cumulative Component Failures	Cumulative % Failure Rate
06/96 - 12/05	*All Types*	*373*	*5533*	*0*			*0.0%*
01/97 - 12/02	**C06 CF**	23	281	0			
2003		5	84	0			
2004		3	54	0			
2005		2	36	0	455	0	0.0%
01/99 - 12/02	**C06 BL**	4	48	0			
2003		1	18	0			
2004		1	18	0			
2005		1	18	0	102	0	0.0%
2003	**C06 UL**	6	108	0			
2004		2	36	0			
2005		2	36	0	180	0	0.0%
01/97 - 12/02	**C08 BL**	27	342	0			
2003		1	18	0			
2004		1	18	0			
2005		2	36	0	414	0	0.0%
06/96 - 12/02	**C11 AH**	33	432	0			
2003		1	18	0			
2004		1	18	0			
2005		1	18	0	486	0	0.0%
06/96 - 12/02	**C11 CF**	29	387	0			
2003		3	54	0			
2004		3	18	0			
2005		1	18	0	477	0	0.0%
2003	**C11 UL**	3	66	0			
2004		3	66	0			
2005		1	18	0	150	0	0.0%
06/96 - 12/02	**C17 AH**	75	1115	0			
2003		2	24	0			
2004		1	12	0			
2005		1	18	0	1169	0	0.0%
06/96 - 12/02	**C17 CF**	49	630	0			
2003		9	156	0			
2004		3	54	0			
2005		5	90	0	930	0	0.0%
2003	**C17 UL**	7	204	0			
2004		6	186	0			
2005		1	18	0	408	0	0.0%
01/97 - 12/02	**C22 CF**	14	186	0			
2003		4	72	0			
2004		1	18	0			
2005		1	18	0	294	0	0.0%
01/97 - 12/02	**C40 AH**	27	324	0			
2003		5	72	0			
2004		1	18	0			
2005		1	18	0	432	0	0.0%

MultiLayer Capacitors – Resistance to Soldering Heat

Data Collection Period	Temperature Characteristic	Number of Lots	Number of Components Tested	Number of Component Failures	Cumulative Components Tested	Cumulative Component Failures	Cumulative % Failure Rate
06/96 - 12/05	*All Types*	*377*	*3523*	*0*			*0.0%*
01/97 - 12/02	**C06 CF**	24	198	0			
2003		5	45	0			
2004		3	27	0			
2005		3	27	0	270	0	0.0%
01/99 - 12/02	**C06 BL**	4	36	0			
2003		1	9	0			
2004		1	9	0			
2005		1	9	0	63	0	0.0%
2003	**C06 UL**	5	45	0			
2004		1	9	0			
2005		2	18	0	72	0	0.0%
01/97 - 12/02	**C08 BL**	25	260	0			
2003		3	27	0			
2004		1	9	0			
2005		2	18	0	314	0	0.0%
06/96 - 12/02	**C11 AH**	34	308	0			
2003		1	9	0			
2004		1	9	0			
2005		1	9	0	326	0	0.0%
06/96 - 12/02	**C11 CF**	2	252	0			
2003		3	27	0			
2004		3	27	0			
2005		5	45	0	351	0	0.0%
2003	**C11 UL**	3	27	0			
2004		3	27	0			
2005		1	9	0	63	0	0.0%
06/96 - 12/02	**C17 AH**	86	776	0			
2003		2	18	0			
2004		1	9	0			
2005		1	9	0	812	0	0.0%
06/96 - 12/02	**C17 CF**	49	441	0			
2003		9	81	0			
2004		3	27	0			
2005		5	45	0	594	0	0.0%
2003	**C17 UL**	7	63	0			
2004		6	54	0			
2005		1	9	0	226	0	0.0%
01/97 - 12/02	**C22 CF**	14	126	0			
2003		4	36	0			
2004		1	9	0			
2005		1	9	0	180	0	0.0%
01/97 - 12/02	**C40 AH**	21	189	0			
2003		5	45	0			
2004		1	9	0			
2005		1	1	0	252	0	0.0%

MultiLayer Capacitors – Resistance to Moisture

Data Collection Period	Temperature Characteristic	Number of Lots	Number of Components Tested	Number of Component Failures	Cumulative Components Tested	Cumulative Component Failures	Cumulative % Failure Rate
06/96 - 12/05	*All Types*	*352*	*3388*	*7*			*0.21%*
01/97 - 12/02	**C06 CF**	21	189	0			
2003		4	36	0			
2004		1	9	0			
2005		3	27	0	261	0	0.0%
01/99 - 12/02	**C06 BL**	4	36	0			
2003		1	9	0			
2004		1	9	0			
2005		1	9	0	63	0	0.0%
2003	**C06 UL**	5	45	0			
2004		1	9	0			
2005		2	18	0	72	0	0.0%
01/97 - 12/02	**C08 BL**	27	246	0			
2003		3	27	0			
2004		1	9	0			
2005		2	18	0	300	0	0.0%
06/96 - 12/02	**C11 AH**	33	296	0			
2003		1	9	0			
2004		1	9	0			
2005		1	9	0	323	0	0.0%
06/96 - 12/02	**C11 CF**	27	225	0			
2003		4	36	0			
2004		2	18	0			
2005		3	27	0	306	0	0.0%
2003	**C11 UL**	3	27	0			
2004		3	27	0			
2005		1	9	0	63	0	0.0%
06/96 - 12/02	**C17 AH**	81	747	0			
2003		2	18	0			
2004		1	9	0			
2005		1	9	0	783	0	0.0%
06/96 - 12/02	**C17 CF**	42	371	7			
2003		2	18	0			
2004		3	27	0			
2005		5	45	0	461	7	1.52%
2003	**C17 UL**	7	63	0			
2004		6	54	0			
2005		1	9	0	126	0	0.00%
1/97 – 12/02	**C22 CF**	14	126	0			
2003		4	36	0			
2004		1	9	0			
2005		1	9	0	216	0	0.00%
01/97 - 12/02	**C40AH**	23	351	0			
2003		5	45	0			
2004		1	9	0			
2005		1	9	0	414	0	0.00%

MultiLayer Capacitors – Low Voltage Humidity

Data Collection Period	Temperature Characteristic	Number of Lots	Number of Components Tested	Number of Component Failures	Cumulative Components Tested	Cumulative Component Failures	Cumulative % Failure Rate
06/96 - 12/05	*All Types*	*267*	*5396*	*3*			*0.05%*
01/97 - 12/02	**C06 CF**	26	438	0			
2003		4	48	0			
2004		1	12	0			
2005		3	36	0	498	0	0.0%
06/99 - 12/02	**C06 BL**	4	72	0			
2003		1	12	0			
2004		1	12	0			
2005		1	12	0	108	0	0.0%
2003	**C06 UL**	5	60	0			
2004		1	12	0			
2005		2	24	0	96	0	0.0%
01/97 - 12/02	**C08 BL**	27	454	2			
2003		3	36	0			
2004		1	12	0			
2005		2	24	0	526	2	0.38%
06/96 - 12/02	**C11 AH**	42	463	1			
2003		1	12	0			
2004		1	12	0			
2005		1	12	0	499	1	0.2%
06/96 - 12/02	**C11 CF**	25	463	0			
2003		4	48	0			
2004		2	24	0			
2005		**3**	36	0	571	0	0.0%
2003	**C11 UL**	3	36	0			
2004		3	36	0			
2005		1	12	0	84	0	0.0%
06/96 - 12/02	**C17 AH**	82	1348	0			
2003		3	36	0			
2004		1	12	0			
2005		1	12	0	1408	0	0.0%
06/96 - 12/02	**C17 CF**	40	612	0			
2003		2	24	0			
2004		3	36	0			
2005		5	60	0	732	0	0.0%
2003	**C11 UL**	7	84	0			
2004		6	72	0			
2005		1	12	0	168	0	0.0%
1/97 – 12/02	**C22 CF**	14	178	0			
2003		4	48	0			
2004		1	12	0			
2005		1	12	0	250	0	0.0%
01/97 - 12/02	**C40 AH**	22	372	0			
2003		5	60	0			
2004		1	12	0			
2005		1	12	0	456	0	0.0%

MultiLayer Capacitors – Life Testing

Data Collection Period	Temperature Characteristic	Number of Lots	Number of Components Tested	Number of Component Failures	Total Test Hour	Cumulative Accelerated Test Hours	Cumulative Component Failures	Cumulative Equivalent Failure Rate	Reliability MTTF: 95% Confidence	Reliability Reliability t = 10 years
06/96 - 12/05	*All Types*	*422*	*16,901*	*0*	*33,802,000*	*270,416,000*	*0*			
	CXXCF	*141*	*6,204*	*0*	*12,408,000*	*99,264,000*	*0*	*0.01%*	*33,135,162*	*99.7%*
	CXXAH	*168*	*6,526*	*0*	*13,052,000*	*104,416,000*	*0*	*0.01%*	*34,854,944*	*99.7%*
	CXXBL	*47*	*2,059*	*0*	*4,118,000*	*32,944,000*	*0*	*0.01%*	*10,996,986*	*99.2%*
	CXXUL	*48*	*2,112*	*0*	*4,224,000*	*33,792,000*	*0*	*0.01%*	*11,280,055*	*99.2%*
01/97 - 12/02	**C06 CF**	22	828	0	1,656,000					
2003		4	176	0	352,000					
2004		1	44	0	88,000					
2005		3	132	0	264,000	18,880,000	0	0.1%	6,302,304	98.6%
01/99 - 12/02	**C06 BL**	11	556	0	1,112,000					
2003		1	44	0	88,000					
2004		1	44	0	88,000					
2005		1	44	0	88,000					
						11,008,000	0	0.1%	3,674,563	97.7%
2003	**C06 UL**	6	264	0	528,000					
2004		7	308	0	616,000					
2005		2	88	0	176,000	10,560,000	0	0.1%	3,535,017	97.6%
01/97 - 12/02	**C08 BL**	27	1107	0	2,178,000					
2003		3	132	0	264,000					
2004		1	44	0	88,000					
2005		2	88	0	176,000					
						21,936,000	0	0.1%	7,322,422	98.8%
06/96 - 12/02	**C11 AH**	47	1811	0	3,622,000					
2003		3	132	0	264,000					
2004		1	44	0	88,000					
2005		1	44	0	88,000					
						32,496,000	0	0.01%	10,847,440	99.2%
06/96 - 12/02	**C11 CF**	30	1137	0	2,274,000					
2003		5	220	0	440,000					
2004		2	88	0	176,000					
2005		3	132	0	264,000	25,323,000	0	0.01%	8,422,655	99.0%
2003	**C11 UL**	12	528	0	1,056,000					
2004		6	264	0	528,000					
2005		1	44	0	88,000	13,376,000	0	0.1%	4,456,022	98.1%

06/96 - 12/02	**C17 AH**	83	3054	0	6,108,000					
2003		3	132	0	264,000					
2004		1	44	0	88,000					
2005		1	44	0	88,000					
						52,384,000	0	0.01%	17,486,272	99.5%
06/96 - 12/02	**C17 CF**	40	1509	0	3,018,000					
2003		2	88	0	176,000					
2004		3	132	0	264,000					
2005		5	220	0	440,000					
						31,184,000	0	0.01%	10,409,483	99.2%
2003	**C17 UL**	7	308	0	616,000					
2004		6	264	0	528,000					
2005		1	44	0	88,000	9,856,000	0	0.1%	3,290,016	97.4%
1/97 – 12/02	**C22 CF**	14	616	0	1,232,000					
2003		4	176	0	352,000					
2004		1	44	0	88,000					
2005		1	44	0	88,000	14,080,000	0	0.1%	4,700,023	98.2%
01/98 - 12/02	**C40AH**	20	913	0	1,826,000					
2003		5	220	0	440,000					
2004		1	44	0	88,000					
2005		1	44	0	88,000	19,336,000	0	0.1%	6,521,282	98.7%

1. Capacitors with rated voltage greater than 500 volts are tested at 1000 volts dc.
2. Equivalent Failure Rate determined from MIL-PRF-55681 in conjunction with MIL-STD-69