

EESTOR INC.

TEST REPORT

SCOPE OF WORK

Performance testing of capacitive samples - ceramic samples called 431-3R, 431-4, 432-6, 434-5A, L-2 # 1056, L-3 # 1062, L-2 # 2000, L-2 # 2001

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TEST REPORT

8/14/2018

Intertek Report No. 103607982DAL-001
Intertek Project No. G103607982

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Subject: Performance testing of capacitive samples - ceramic samples called 431-3R, 431-4, 432-6, 434-5A, L-2 # 1056, L-3 # 1062, L-2 # 2000, L-2 # 2001.

Dear Bryan Kelly,

This letter report represents the results of our evaluation of the above referenced samples.

SECTION 1 SUMMARY

Eight unique samples were tested at the EESTOR Inc. facility at 715 Discovery Blvd. Ste: 107, Cedar Park, Texas, 78613, USA on the 6th and 7th August 2018. The samples were identified as 431-3R, 431-4, 432-6, 434-5A, L-2 # 1056, L-3 # 1062, L-2 # 2000, L-2 # 2001. The samples were subjected to the measurements outlined in the section 2 of this report.

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TEST REPORT

SECTION 2
TESTING

The items below represent a summary of the tests and results.

Test Location: 715 Discovery Blvd. Ste:107, Cedar Park, Texas 78613

Test Date: 08/06/2018 – 08/07/2018

Test Site Ambient Conditions: 24°C to 25°C, 52%RH

Parameters measurement

Sample ID: 431-3R

VAC Parameters for Sample ID: 431-3R					
Measured				Calculated	
Electrode Shape:		Round			
Electrode diameter (mm):		3.6			
Dielectric thickness (µm):		960			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/µm)
1	1000	0.0100	0.131	1395	0.001
30	60	0.0130	0.128	1363	0.044
75	60	0.0200	0.130	1385	0.110
100	60	0.0230	0.131	1395	0.147
300	60	0.0270	0.136	1449	0.442
1000	60	0.0270	0.143	1523	1.473
1500	60	0.0300	0.145	1545	2.210

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VDC Parameters for Sample ID: 431-3R							
Measured			Calculated				
Electrode Shape:		Round					
Electrode diameter (mm):		3.6					
Dielectric thickness (µm):		960					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/µm)	Energy Density (Wh/l)	Time Constant (s)
75	0.2	0.1	750	2130	0.1	0.00	150
100	0.2	0.2	500	2130	0.1	0.00	100
500	0.203	1.2	417	2162	0.5	0.00	85
1000	0.199	3.0	333	2120	1.0	0.00	66
2000	0.195	8.4	238	2077	2.1	0.01	46
3000	0.179	17	176	1907	3.1	0.02	32
4000	0.175	26	154	1864	4.2	0.04	27
5000	0.165	37	135	1758	5.2	0.06	22
6000	0.160	50	120	1704	6.3	0.08	19
7000	0.157	64	109	1672	7.3	0.11	17
8000	0.150	76	105	1598	8.3	0.14	16
9000	0.145	93	97	1545	9.4	0.17	14
10000	0.150	107	93	1598	10.4	0.21	14
11000	0.143	127	87	1523	11.5	0.25	12
12000	0.147	140	86	1566	12.5	0.30	13
13000	0.133	163	80	1417	13.5	0.32	11
14000	0.135	187	75	1438	14.6	0.38	10
15000	0.142	212	71	1513	15.6	0.45	10

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Sample ID: 431-4

VAC Parameters for Sample ID: 431-4					
Measured				Calculated	
Electrode Shape:		Round			
Electrode diameter (mm):		3.8			
Dielectric thickness (µm):		960			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/µm)
1	1000	0.0530	0.168	1606	0.001
30	60	0.0070	0.163	1558	0.044
75	60	0.0080	0.165	1577	0.110
100	60	0.0100	0.165	1577	0.147
200	60	0.0150	0.169	1616	0.295
300	60	0.0160	0.172	1644	0.442
1000	60	0.0190	0.175	1673	1.473
2000	60	0.0230	0.175	1673	2.946

VDC Parameters for Sample ID: 431-4							
Measured			Calculated				
Electrode Shape:		Round					
Electrode diameter (mm):		3.8					
Dielectric thickness (µm):		960					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/µm)	Energy Density (Wh/l)	Time Constant (s)
75	0.3	0.4	188	2868	0.1	0.00	56
500	0.293	3.1	161	2801	0.5	0.00	47
1000	0.269	7.8	128	2572	1.0	0.00	34
2000	0.255	22	91	2438	2.1	0.01	23
3000	0.23	39	77	2199	3.1	0.03	18
4000	0.211	60	67	2017	4.2	0.04	14
5000	0.204	82	61	1950	5.2	0.07	12
6000	0.197	100	60	1883	6.3	0.09	12
7000	0.19	130	54	1816	7.3	0.12	10
8000	0.195	145	55	1864	8.3	0.16	11
9000	0.184	170	53	1759	9.4	0.19	10
10000	0.168	197	51	1606	10.4	0.21	9
10500	Breakdown at 10497V						

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Sample ID: 432-6

VAC Parameters for Sample ID: 432-6					
Measured				Calculated	
Electrode Shape:		Round			
Electrode width (mm):		5.5			
Dielectric thickness (μm):		675			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/μm)
1	1000	0.0160	0.353	1133	0.002
30	60	0.0160	0.357	1146	0.063
75	60	0.0160	0.359	1152	0.157
100	60	0.0170	0.361	1158	0.210
200	60	0.0190	0.366	1174	0.419
500	60	0.0230	0.373	1197	1.048
1000	60	0.0190	0.375	1203	2.095
1500	60	0.0220	0.371	1190	3.143

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VDC Parameters for Sample ID: 432-6							
Measured			Calculated				
Electrode Shape:		Round					
Electrode diameter (mm):		5.5					
Dielectric thickness (µm):		675					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/µm)	Energy Density (Wh/l)	Time Constant (s)
75	0.4	0.1	750	1284	0.1	0.00	300
100	0.4	0.1	1000	1284	0.1	0.00	400
200	0.4	0.1	2000	1284	0.3	0.00	800
300	0.4	0.1	3000	1284	0.4	0.00	1200
500	0.406	0.2	2500	1303	0.7	0.00	1015
600	0.413	0.3	2000	1325	0.9	0.00	826
900	0.409	0.4	2250	1312	1.3	0.00	920
1100	0.412	0.5	2200	1322	1.6	0.00	906
1300	0.411	0.6	2167	1319	1.9	0.01	891
1500	0.409	0.5	3000	1312	2.2	0.01	1227
2000	0.405	0.6	3333	1300	3.0	0.01	1350
3000	0.391	1.1	2727	1255	4.4	0.03	1066
4000	0.374	1.6	2500	1200	5.9	0.05	935
5000	0.357	1.8	2778	1146	7.4	0.08	992
6000	0.341	2.3	2609	1094	8.9	0.11	890
7000	0.325	3.3	2121	1043	10.4	0.14	689
8000	0.312	4.7	1702	1001	11.9	0.17	531
9000	0.299	5.3	1698	959	13.3	0.21	508
10000	0.288	5	2000	924	14.8	0.25	576
11000	0.281	5.6	1964	902	16.3	0.29	552
12000	0.268	4.9	2449	860	17.8	0.33	656
13000	0.258	5.9	2203	828	19.3	0.38	568
14000	0.251	5.7	2456	805	20.7	0.43	616
15000	0.244	6.4	2344	783	22.2	0.48	572

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Sample ID: 434-5A

VAC Parameters for Sample ID: 434-5A					
Measured				Calculated	
Electrode Shape:		Round			
Electrode width (mm):		2.0			
Dielectric thickness (μm):		27			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/μm)
1	1000	0.0146	1.03	1000	0.052
30	60	0.0400	1.12	1087	1.571
50	60	0.0500	1.13	1097	2.619
75	60	0.0510	1.14	1107	3.928
100	60	0.0550	1.12	1087	5.238
200	60	0.0610	1	971	10.476
300	60	0.0600	0.898	872	15.713

VDC Parameters for Sample ID: 434-5A							
Measured				Calculated			
Electrode Shape:		Round					
Electrode diameter (mm):		2.0					
Dielectric thickness (μm):		27					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/μm)	Energy Density (Wh/l)	Time Constant (s)
75	1.5	0.9	83	1456	2.8	0.01	125
100	1.4	1.1	91	1359	3.7	0.02	127
300	1.16	3	100	1126	11.1	0.17	116
500	0.88	5	100	854	18.5	0.36	88
750	0.72	7.7	97	699	27.8	0.66	70
1000	0.61	11.7	85	592	37.0	1.00	52
1250	0.52	30	42	505	46.3	1.33	22
1500	0.34	81	19	330	55.6	1.25	6
1750	Breakdown						

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Sample ID: L-2 # 1056

VAC Parameters for Sample ID: L-2 # 1056					
Measured				Calculated	
Electrode Shape:		Round			
Electrode width (mm):		4.4			
Dielectric thickness (µm):		580			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/µm)
1	1000	0.0090	7.93	34163	0.002
30	60	0.0410	8.64	37222	0.073
75	60	0.0150	8.33	35886	0.183
100	60	0.0120	7.97	34335	0.244
300	60	0.0170	5.25	22617	0.731
500	60	0.0260	3.81	16414	1.219
1000	60	0.0420	2.32	9995	2.438
1500	60	0.0520	1.7	7324	3.657

VDC Parameters for Sample ID: L-2 # 1056							
Measured			Calculated				
Electrode Shape:		Round					
Electrode diameter (mm):		4.4					
Dielectric thickness (µm):		580					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/µm)	Energy Density (Wh/l)	Time Constant (s)
75	8.6	0.1	750	37050	0.1	0.00	6450
100	8.3	0.1	1000	35757	0.2	0.00	8300
150	7.6	0.1	1500	32741	0.3	0.00	11400
200	6.8	0.1	2000	29295	0.3	0.00	13600
250	6.2	0.1	2500	26710	0.4	0.01	15500
300	5.6	0.2	1500	24125	0.5	0.01	8400
500	3.9	0.2	2500	16802	0.9	0.02	9750
750	2.8	0.3	2500	12063	1.3	0.02	7000
1000	2.2	0.6	1667	9478	1.7	0.03	3667
1500	1.47	0.6	2500	6333	2.6	0.05	3675
2000	1.12	0.5	4000	4825	3.4	0.07	4480
3000	0.774	0.6	5000	3334	5.2	0.11	3870
4000	0.535	1.3	3077	2305	6.9	0.13	1646
5000	Breakdown						

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Sample ID: L-3 # 1062

VAC Parameters for Sample ID: L-3 # 1062					
Measured				Calculated	
Electrode Shape:		Round			
Electrode diameter (mm):		3.8			
Dielectric thickness (µm):		560			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/µm)
1	1000	0.0077	5.08	28330	0.003
30	60	0.0360	5.57	31063	0.076
75	60	0.0170	5.39	30059	0.189
100	60	0.0130	5.18	28888	0.253
200	60	0.0090	4.23	23590	0.505
300	60	0.0100	3.48	19407	0.758
500	60	0.0140	2.56	14277	1.263
1000	60	0.0260	1.57	8756	2.525

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VDC Parameters for Sample ID: L-3 # 1062							
Measured			Calculated				
Electrode Shape:		Round					
Electrode diameter (mm):		3.8					
Dielectric thickness (µm):		560					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/µm)	Energy Density (Wh/l)	Time Constant (s)
75	5.5	0.1	750	30672	0.1	0.00	4125
100	5.4	0.1	1000	30115	0.2	0.00	5400
150	4.9	0.1	1500	27326	0.3	0.00	7350
200	4.4	0.1	2000	24538	0.4	0.00	8800
250	4	0.1	2500	22307	0.4	0.01	10000
300	3.6	0.1	3000	20076	0.5	0.01	10800
350	3.3	0.1	3500	18403	0.6	0.01	11550
550	2.37	0.2	2750	13217	1.0	0.02	6518
700	1.97	0.2	3500	10986	1.3	0.02	6895
850	1.68	0.3	2833	9369	1.5	0.03	4760
1000	1.45	0.3	3333	8086	1.8	0.03	4833
1150	1.27	0.3	3833	7082	2.1	0.04	4868
1300	1.14	0.4	3250	6358	2.3	0.04	3705
1500	0.994	0.3	5000	5543	2.7	0.05	4970
2000	0.746	0.4	5000	4160	3.6	0.07	3730
2500	0.585	0.1	25000	3262	4.5	0.08	14625
3000	0.506	0.6	5000	2822	5.4	0.10	2530
3500	0.428	0.4	8750	2387	6.3	0.11	3745
4000	0.378	0.9	4444	2108	7.1	0.13	1680
4500	0.339	0.8	5625	1891	8.0	0.15	1907
5000	0.306	0.8	6250	1706	8.9	0.17	1913
5500	0.279	0.8	6875	1556	9.8	0.18	1918
6000	0.255	1.1	5455	1422	10.7	0.20	1391
6500	Breakdown						

TEST REPORT

Sample ID: L-2 # 2000

VAC Parameters for Sample ID: L-2 # 2000					
Measured				Calculated	
Electrode Shape:		Round			
Electrode diameter (mm):		6.0			
Dielectric thickness (μm):		595			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/μm)
1	1000	0.0220	3.08	7320	0.002
30	60	0.0780	3.67	8723	0.071
75	60	0.1210	4.22	10030	0.178
100	60	0.1100	4.39	10434	0.238
200	60	0.1130	4.72	11218	0.475
300	60	0.1010	4.58	10885	0.713
500	60	0.0780	4.03	9578	1.188
1000	60	0.0510	2.96	7035	2.377
1500	60	0.0500	2.33	5538	3.565

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VDC Parameters for Sample ID: L-2 # 2000							
Measured			Calculated				
Electrode Shape:		Round					
Electrode diameter (mm):		6.0					
Dielectric thickness (µm):		595					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/µm)	Energy Density (Wh/l)	Time Constant (s)
75	5.2	0.3	250	12359	0.1	0.00	1300
100	4.4	0.3	333	10458	0.2	0.00	1467
200	5.1	0.3	667	12121	0.3	0.00	3400
300	4.8	0.3	1000	11408	0.5	0.00	4800
500	4.2	0.5	1000	9982	0.8	0.01	4200
1000	3.1	9	111	7368	1.7	0.03	344
2000	2.0	1.8	1111	4753	3.4	0.07	2222
3000	1.47	2.6	1154	3494	5.0	0.11	1696
4000	1.15	5	800	2733	6.7	0.15	920
5000	0.95	2.6	1923	2258	8.4	0.20	1827
6000	0.81	4.7	1277	1925	10.1	0.24	1034
7000	0.70	3.5	2000	1664	11.8	0.28	1400
8000	0.62	3.6	2222	1474	13.4	0.33	1378
9000	0.56	3.2	2813	1331	15.1	0.37	1575
10000	0.50	4.1	2439	1188	16.8	0.41	1220
11000	0.46	4.1	2683	1093	18.5	0.46	1234
12000	Breakdown						

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Sample ID: L-2 # 2001

VAC Parameters for Sample ID: L-2 # 2001					
Measured				Calculated	
Electrode Shape:		Round			
Electrode diameter (mm):		5.4			
Dielectric thickness (μm):		560			
Voltage AC (V rms)	Frequency (Hz)	Dissipation Factor DF	Capacitance C (nF)	Relative permittivity k	Electric Field (Vpk/μm)
1	1000	0.0120	2.49	6876	0.003
30	60	0.0500	2.92	8064	0.076
75	60	0.1050	3.53	9748	0.189
100	60	0.1060	3.76	10384	0.253
200	60	0.1100	4.05	11185	0.505
300	60	0.0970	3.92	10826	0.758
500	60	0.0720	3.43	9472	1.263
1000	60	0.0440	2.5	6904	2.525
1500	60	0.0380	1.95	5385	3.788

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VDC Parameters for Sample ID: L-2 # 2001							
Measured			Calculated				
Electrode Shape:		Round					
Electrode diameter (mm):		5.4					
Dielectric thickness (µm):		560					
Voltage DC (V)	Capacitance C (nF)	Leakage current (nA)	Resistance iR (GΩ)	Relative permittivity k	Electric Field (V/µm)	Energy Density (Wh/l)	Time Constant (s)
75	3.80	0.1	750	10494	0.1	0.00	2850
100	3.60	0.1	1000	9942	0.2	0.00	3600
200	3.95	0.2	1000	10908	0.4	0.00	3950
300	3.78	0.3	1000	10439	0.5	0.00	3780
500	3.36	0.3	1667	9279	0.9	0.01	5600
1000	2.55	0.6	1667	7042	1.8	0.03	4250
2000	1.63	1.3	1538	4501	3.6	0.07	2508
3000	1.18	1.9	1579	3259	5.4	0.12	1863
4000	0.92	3.0	1333	2541	7.1	0.16	1227
5000	0.76	3.0	1667	2099	8.9	0.21	1267
6000	0.65	3.3	1818	1795	10.7	0.25	1182
7000	0.65	4	1750	1795	12.5	0.34	1138
8000	0.5	4	2000	1381	14.3	0.35	1000
9000	0.45	4.1	2195	1243	16.1	0.39	988
10000	0.41	4	2500	1132	17.9	0.44	1025
11000	0.37	4.4	2500	1022	19.6	0.48	925
12000	0.34	5.1	2353	939	21.4	0.53	800
13000	0.32	4	3250	884	23.2	0.59	1040
14000	0.3	4.6	3043	828	25.0	0.64	913
15000	0.28	6.3	2381	773	26.8	0.68	667

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SECTION 3

CALCULATIONS/RESULTS

The items below represent calculations based on test results.

Formula used to find relative permittivity of the dielectric material (k):

1) $k = dC / \epsilon_0 A$

Where:

d = Sample thickness (m)

C = Measured capacitance (F)

ϵ_0 = Permittivity of space (8.854×10^{-12} F/m)

A = Area of circular plate based on measured diameter (m²)

Formula used to find Energy Density W of the sample (Wh/ Liter):

1) Energy W in Joule = $1/2 CV^2$

Where

C = Measured capacitance (F)

V = Measured peak voltage (V)

2) Volume in cm³ / m³ = Area x Thickness x 1,000,000

Where

Area of electrode = Calculated in m²

Thickness of electrode = Calculated in meter

3) Energy density Wh/Litre = (Energy W in Joule/3600) / (Volume in cm³/m³/1000)

SECTION 4

PROJECT STATUS & ACTION

Issuance of this letter report completes the testing portion covered by Intertek Project No. G103607982.

If there are any questions regarding the results contained in this report, or any of the other services offered by Intertek, please do not hesitate to contact your dedicated Intertek Project Engineer.

Completed by:	Zbigniew Musial	Reviewed by:	Brandon DeVaul
Title:	Project Engineer	Title:	Project Reviewer
Signature:		Signature:	
Date:	08/14/2018	Date:	08/14/2018