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EEStor: New Capacitor Technology for Bypass, Decoupling, Filtering and Energy Storage

EEStor Designs a More Efficient Hybrid CMBT-Glass Capacitor Technology for Next Generation Medium and High Voltage Industrial Electronics

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Capacitor Technology for Next Generation Medium and

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Capacitors are an essential component found in all electrical and electronic systems and represent a $23 Billion USD market worldwide[1]. They are used for bypassing, decoupling, DC and AC filtering and energy storage/discharge circuits in modern power supplies. The trend towards the continued electrification of the automotive, energy and consumer electronics sectors is expected to generate significant demand for such capacitors for the foreseeable future.

EEStor Corporation (TSXV:ESU), a capacitor dielectric and component innovator, has developed a proprietary ceramic dielectric material that when used as a capacitor dielectric demonstrates a significant higher relative permittivity than commercially-available Y5V type ceramic capacitors. " Y5V dielectrics in general have high capacitance per unit volume, and have a wide temperature characteristic of +22% –82% capacitance change over the operating temperature range of –30°C to +85°C (-22°F to +185°F). These characteristics make Y5V ideal for decoupling applications within limited temperature ranges. "[2] EEStor CMBT-glass hybrid Y5V series capacitors have higher volumetric efficiency, lower dissipation factors and better frequency stability than current commercial Y5V dielectrics making them ideally suited for circuits requiring greater volumetric efficiency or greater capacitance at high voltage. Y5V capacitors represent $1.5 billion (USD) of the $23 billion (USD) global capacitor market in 2018.[1]

Third Party Testing and Validation

EEStor Composite Modified Barium Titanate (CMBT) Y5V dielectric materials have been tested extensively over a 3-month period by three independent parties - Intertek, Radiant Technologies and MRA Laboratories. To learn more about test results, visit eestorcorp.com.

Applications for Decoupling Capacitors

Y5V capacitors are used for moderate temperature applications where high capacitance and low dissipation factor are critical to the circuit design. The primary aspect of EEStor Y5V capacitors that makes them useful in this application is the capacitance per unit volume, especially at high voltage.

EEStor has developed a [case study of one decoupling application, Electromagnetic Compatibility Systems,] to illustrate the applications of Y5V capacitors.

Direct Comparisons of EEStor Decoupling Capacitors to Commercial Technology

MRA Laboratories tested EEStor dielectric capacitor layers for thermal performance and measured the Temperature Coefficient of Capacitance (TCC). TCC describes the maximum change in capacitance over a specified temperature range. EEStor dielectrics can be classified in the Electronic Industries Alliance (EIA) RS-198 standards as a Y5V or Y6V designation based on the following data:

- Y5V because at -30°C it has a TCC of -80.4%, and at 85°C it has a TCC of -66.7%
- Y6V because at -30°C it has a TCC of -80.4%, and at 105°C it has a TCC of -71.9%

400 V AC disc capacitor

Based upon the test results above, EEStor has been able to design a CMBT-based capacitor that can compete against commercially available Y5V 400 V AC ceramic disc capacitors which are over four times the volume. This size difference translates directly to a lower cost per farad, as significantly less material will be used for the smaller volume EEStor component. In addition to having higher capacitance per unit volume and lower cost per farad, the **EEStor Y5V disc capacitor has a lower dissipation factor, higher insulation resistance, and a higher breakdown strength than the comparable commercial capacitor**. Technical results supporting this conclusion can be found in the Appendix.

50 V DC multi-layer ceramic capacitor

Another example of the benefits of an EEStor capacitor over existing technologies is also apparent when compared with commercial Y5V 50 V DC multi-layer ceramic capacitors (MLCC). Commercial Y5V MLCCs have 8% less capacitance for the same size as the EEStor 50 V DC Y5V MLCC. **The EEStor MLCC has higher insulation resistance, 8% more capacitance, and better DC bias characteristics than the commercially available Y5V MLCC.** Technical results can be found in the Appendix.

Summary

When comparing EEStor dielectrics to other ceramic capacitor products on the market, EEStor capacitor technology demonstrates superior performance in key areas:

- EEStor dielectrics have a higher relative dielectric constant than comparable dielectrics on the market today,
- EEStor dielectrics demonstrate a lower dissipation factor than comparable capacitors in test results (by a wide margin), and

- EEStor dielectrics have higher insulation resistance than comparable capacitors.

About EEStor

EEStor is a developer of high energy density solid-state capacitor technology utilizing the company's patented Composition Modified Barium Titanate (CMBT) material. The company is focused on licensing opportunities for its technology across a broad spectrum of industries and applications.

The Company's success depends on the commercialization of its technology. There is no assurance that EEStor will be successful in the completion of the various enhancement phases underway to warrant the anticipated licensing opportunities in the technology. Readers are directed to the "Risk Factors" disclosed in the Company's public filings.

1. EEStor On Site Presentation - May 6, 2018
2. http://datasheets.avx.com/Y5V.pdf

Appendix

Test #3: Temperature Coefficient of Capacitance
(@ 1 kHz and 1 MHz, -55°C – 200°C temperature range, 0V dc-bias)

Temp., °C	CS-18-2 (#377-3)			
	1kHz		1MHz	
	Cap, %	DF, %	Cap, %	DF, %
-55	-89.63	4.70	-	-
-45	-87.12	4.29	-	-
-35	-83.37	4.07	-	-
-25	-77.64	3.84	-	-
-15	-66.80	3.64	-	-
-5	-43.04	3.63	-	-
5	-13.50	3.11	-	-
15	1.35	2.11	-	-
25	0.00	1.41	-	-
35	-5.80	1.00	-	-
45	-19.05	0.68	-	-
55	-34.82	0.43	-	-
65	-49.25	0.27	-	-
75	-59.95	0.19	-	-
100	-76.77	0.11	-	-
125	-84.93	0.10	-	-
150	-89.72	0.12	-	-
175	-97.72	0.14	-	-
200	-99.22	0.24	-	-
Used equipment: HP 4278A Capacitance meter and Delta 9023 environmental chamber. Measured uncertainty: C, DF ±0.25%. Room temperature: 19.1°C. Relative humidity: 14.3%.				

Note: TCC measurements at 1MHz were not performed because the capacitance of the sample exceeded the acceptable limit of the capacitance meter.

Test #5: INSULATION RESISTANCE
(@ 1000V, RT and 125°C)

Electrical Parameters	CS-18-2 (#377-3)
Room Temperature	
IR, Ω	$8.10*10^{11}$
ρ, Ω*m	$5.32*10^{10}$
R*C, MΩ*μF	9977
125°C	
IR, Ω	$3.55*10^{11}$
ρ, Ω*m	$2.33*10^{10}$
R*C, MΩ*μF	3140
Used equipment: Beckman Megaohmmeter and Delta 9023 environmental chamber. Measured uncertainty: IR ±0.25%. Room temperature: 19.1°C. Relative humidity: 14.3%.	

Technical results of comparison with 1 nano-farad 400 V AC commercial disc capacitor Vishay 125LD10-R

The data sheet for the Vishay 400 V 1 nano-farad, 125LD10-R capacitor (http://www.vishay.com/capacitors/list/product-23106) indicates that the package has a diameter of 8.4 mm and a thickness of 2.4 mm. That's an area of $\pi \times 4.2^2 = 55.418\ mm^2$. And thus, a volume of $55.418\ mm^2 \times 2.4\ mm = 133\ mm^3$ for the whole package.

If we assume that the capacitor has an internal active area equal to the diameter of the finished part, we are surely overestimating the size of the active area, as the area of the capacitor would include the non-zero thickness of the insulation for the layer. The dielectric thickness will also be less than that of the finished part as there is some non-zero value for thickness of the electrodes and packaging. One can't know for sure how much of the Vishay package volume is used by the dielectric. But the data sheet gives some idea how the size grows:

The 5 nano-farad Vishay capacitor package diameter grows to 11 mm from 8.4 mm for the 1 nano-farad capacitor. So, the area (and thus volume) grows $5.5^2 / 4.2^2 = 1.7$ times.

Similarly, the 10 nano-farad Vishay capacitor diameter grows to 14.3 mm from 8.4 mm for the 1 nano-farad capacitor. So, the area (and thus volume) grows $7.15^2 / 4.2^2 = 2.9$ times.

This suggests that the volume of the packaging doesn't grow proportionally with that of the dielectric but stays at about the same thickness as the dielectric grows (which would make sense for a given voltage rating) so that the proportion of the capacitor volume attributed to packaging is reduced as the dielectric volume grows. A rough mathematic regression suggests that at 1 nano-farad, the dielectric would use at least 25% of the volume of the capacitor package.

Therefore, with the dielectric using about 25% of the Vishay whole package volume, that would represent $133\ mm^3 / 4 = 33.25\ mm^3$.

An EEStor 1 nano-farad 400 V disc capacitor built from material from sample 377-3 tested in MRA phase 7a would feature the following performance:

Customer Samples Dimensions

Sample ID#	Customer ID#	Electrode dimensions (diameter or length and width), mm	Sample thickness, mm	Electrodes area, mm^2
CS-18-2	**#377-3**	7.29	0.64	41.737
Used equipment: Precision micrometer, 210-A. Measured uncertainty: ±0.001mm. Room temperature: 19.1°C. Relative humidity: 14.3%.				

Test #2: Capacitance & Dissipation Factor vs. dc-bias (up to 1000V)
(@ 1 kHz, room temperature)

dc-bias, V	CS-18-2 (#377-3)	
	Cap, nF	**DF, %**
0	12.317	0.843
100	11.286	0.943
200	7.579	0.752
300	5.125	0.668
400	3.666	0.604
500	2.782	0.562
600	2.218	0.545
700	1.846	0.528
800	1.580	0.512
900	1.381	0.507
1,000	1.234	0.501
Used equipment: Keysight E4980A precision LCR meter. Measured uncertainty: C, DF ±0.1%. Room temperature: 19.1°C. Relative humidity: 14.3%.		

That EEStor sample was 640 microns thick with an electrode area of 41.737 mm^2 and had a capacitance of 3.666 nano-farads at 400 volts. It also demonstrated a breakdown strength of over 2400 V AC, which is higher than the Vishay capacitor in the comparison.

To build a 1 nano-farad capacitor out of this dielectric material using the same thickness, the area can be reduced to 41.737 mm^2 x 1 nF / 3.666 nF = 11.385 mm^2.

The dielectric volume (area x thickness) would then be: 11.385 mm^2 x 0.64 mm = 7.3 mm^3.

That's a diameter of $(11.385 / \pi)^{½}$ x 2 = 3.8 mm, for a thickness of 640 µm.

We roughly evaluated above that the dielectric of the Vishay capacitor was using at least 25% of its package volume, which is 133 mm^3 / 4 = 33.25 mm^3.

Considering the EEStor dielectric volume of 7.3 mm^3, Vishay would use 33.25 / 7.3 = 4.5 times EEStor's dielectric volume.

In addition to having higher capacitance per unit volume and thus lower cost per farad, the EEStor capacitor has a lower dissipation factor, higher insulation resistance, and a higher breakdown strength than the commercial capacitor.

Technical results of comparison of 1 micro-farad 50 V DC commercial MLCC capacitor AVX (1206 5 G 105 Z A T 2A)

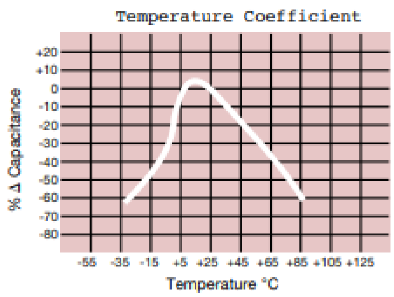
A MLCC made of EEStor's dielectric from sample 361-1 that has a K of 2804 and an insulation resistance of 4286 giga ohms at a field of 5 volts per micron would have the following specification:

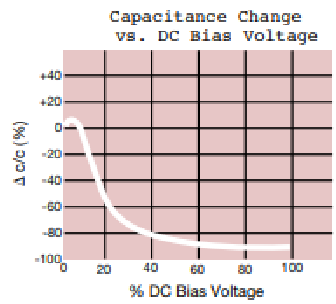
Package Length =	3.20	mm
Package Width =	1.60	mm
Package Height =	1.27	mm
Dielectric Thickness =	10.00	µm
Conductor Thickness =	5.00	µm
k =	2,804	
Dielectric Resistivity =	4.29E+12	Ω-m
Voltage =	50.00	V

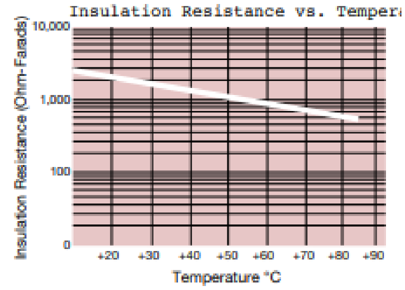
Field =	5.00	V/µm
One Layer Area =	0.0512	cm2/layer
Number of Layers =	85	layers
Total Area of Layers =	4.352	cm2
Part Volume =	0.0065	cm3
Layer Specific Capacitance =	248.2	nF/cm2
One Layer Capacitance =	12.71	nF/layer
Total Capacitance =	1,080.0	nF
Total Resistance =	9.85E+10	Ω
Leakage Current =	0.51	nA
Time Constant =	106,359	sec

The AVX part is using about the same package dimensions for 1 micro farad. However, the resistance of the AVX capacitor is listed as 10 giga-ohms, while EEStor has an expected 98.5 giga-ohm resistance. The EEStor part has higher insulation resistance and will not age over time like the ferroelectric AVX capacitor. While both capacitors drop about the same with respect to temperature since both are Y5V class, EEStor Y5V dielectrics drop much less with voltage bias than the AVX commercial Y5V capacitors.

At a DC bias of 100 volts, the AVX Y5V capacitor with the largest rated voltage of 50 V DC has dropped by 90% (http://datasheets.avx.com/Y5V.pdf). The EEStor capacitance dropped by only 8% at a DC bias of 100 volts (11,286/12,317 = 92%).







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