Advantages of Vishay vs. Competing X1 / Y2 Multilayer Ceramic Safety Capacitors

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A COMPARATIVE STUDY OF 2220 CASE SIZE, X7R, 250 V_{AC} RATED X1 / Y2 SAFETY CAPACITORS (VISHAY AND THREE COMPETITORS)

ABSTRACT

Class X / Y safety capacitors are used in automotive, industrial, and commercial AC line filtering and control applications. This special class of capacitor requires unique certificates of compliance as specified by IEC 60384-14 and CAN/CSA - 60384-14. The X / Y capacitors are placed across the AC input either line to line, or line to chassis / ground, for the suppression of electromagnetic (EFI) and radio frequency interference (RFI). They are referred to as safety capacitors because they have an exceptional design construction that enables them to withstand rigorous lightning surge suppression and AC line spikes, while providing safe decoupling of harmful transients to protect humans from potential hazardous shocks. Many explanations about X / Y safety capacitor classifications are available. Classifications provide specific references for line placement, function, voltage ratings, and certified surge suppression levels. [1]

Vishay provides Class X / Y safety capacitors with many classification offerings in various technologies. Our safety capacitor portfolio includes ceramic disc, ceramic surface-mount, and polypropylene film types. This study is a comparative study of safety class multilayer ceramic capacitors (MLCC) from Vishay and three other manufacturers. All MLCCs evaluated are in the 2220 case size, feature an X7R dielectric, and are 250 V_{AC} rated and classified as X1 / Y2 safety capacitors.

Differences in design materials are present in each manufacturer's respective part number. The purpose of this study is to determine if any specific performance advantage or deficit exists within each respective manufacturer's electrical properties. After a physical examination of capacitor material properties, all capacitors are subject to electrical testing. Electrical tests included impulse voltage per IEC 60384-14, voltage coefficient of capacitance (VCC), and insulation resistance (IR) at 25 °C to 125 °C. The results of testing showed that Vishay capacitors have a higher impulse voltage breakdown level for most samples. Vishay capacitors also retained more capacitance during VCC testing and experienced IR increases at 125 °C, whereas all competitor parts showed a reduction of IR at 125 °C. These advantageous results for Vishay may be attributed to our dielectric material system and the use of precious metal electrode (PME) technology, in contrast to the base metal electrode (BME) systems used by competitors.

INTRODUCTION

The datasheets for Class X / Y safety capacitors from Vishay and three other competitors indicate uses in telecom, automotive, medical, and industrial applications. They are extensively used in power supplies, AC line electromagnetic interference (EMI) filtering, electric vehicle (EV) charging systems, appliances, and more. The Vishay part numbers tested in this study include the VJ2220Y102KXUSTX1, VJ2220Y222KXUSTX1, VJ2220Y332KXUSTX1, and VJ2220Y472KXUSTX1. These values were selected because they are commonly used and some of the competitors' part numbers were readily available. A description of the competitive parts available and tested are referenced as Competitors 1, 2, and 3, and are provided in Table 1.

TABLE 1 - SAFETY CAPACITORS TESTED

MANUFACTURER	VISHAY PART NUMBER	PART DESCRIPTION
Vishay	2220Y102KXUSTX1	2220, X7R, 1.0 nF, 250 V_{AC}, X1 / Y2
Competitor 1		
Competitor 2		
Vishay	2220Y222KXUSTX1	2220, X7R, 2.2 nF, 250 V_{AC}, X1 / Y2
Competitor 1		
Competitor 2		
Competitor 3		
Vishay	2220Y332KXUSTX1	2220, X7R, 3.3 nF, 250 V_{AC}, X1 / Y2
Competitor 1		
Vishay	2220Y472KXUSTX1	2220, X7R, 4.7 nF, 250 V_{AC}, X1 / Y2
Competitor 1		
Competitor 2		

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IMPULSE TESTING

Rigorous surge voltage compliance is demanded of all safety capacitors, which must meet various levels of impulse voltage based on their classification. Most tested competitors met the required impulse voltage level of 5 kV, except for Competitor 1's 2.2 nF device. For the impulse test, Vishay applied a gradual increase in impulse voltage to each capacitor, which revealed differences in the maximum impulse levels that induced dielectric breakdown for each competitor. The impulse voltage was applied in accordance with IEC 60384-14. The impulse waveform is commonly referred to as a lightning surge and must meet rise and decay rates specified in IEC 60060-1:2010, 7.1.18, as depicted in Figure 1. Starting at 5 kV, every capacitor received 3 pulses occurring at 10 s intervals. If the capacitor survived, the impulse level was raised in increments of 250 V. This was repeated until a failure occurred.

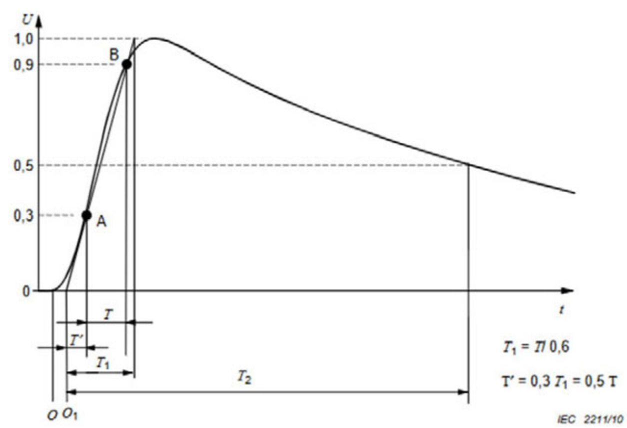

Fig. 1 - Impulse voltage per IEC-60060-1:2010

RESULTS OF IMPULSE TESTING

TABLE 2 - AVERAGE IMPULSE BREAKDOWN VOLTAGE (IBV) OF 2220 SAFETY CAPACITORS [2]				
CAPACITANCE (nF)	VISHAY (V)	COMPETITOR 1 (V)	COMPETITOR 2 (V)	COMPETITOR 3 (V)
1	> 8500	6944	8000	n/a
2.2	8000	6275	6675	6950
3.3	7600	n/a	n/a	6659
4.7	6850	6725	6125	n/a

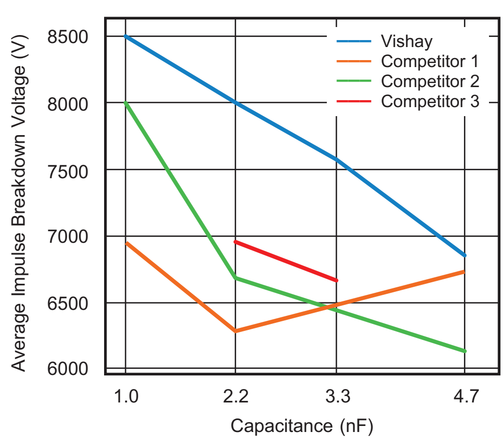

Fig. 2.0 - Average impulse breakdown levels vs. capacitance of 2220 safety capacitors

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Referring to Table 1.0, Vishay's 1 nF IBV is more than 500 V greater than the two competitors tested. It is indicated that Vishay's IBV is > 8500 V because the test equipment is limited to 8500 V and no Vishay failures occurred. Vishay's IBV for the 2.2 nF part is over 1000 V greater than all competitors. For 3.3 nF, the only competing part is available from Competitor 3. Vishay's IBV at 3.3 nF is over 900 V greater than Competitor 3. At 4.7 nF, Vishay's IBV outperforms the two competitors available.

IMPULSE TESTING CUMULATIVE FAILURE LEVELS

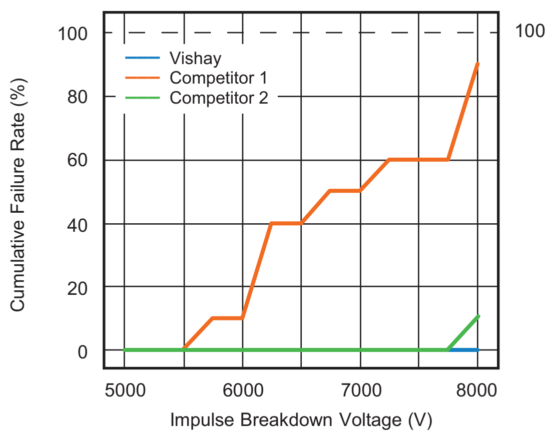

Fig. 2.1 - Impulse breakdown cumulative failures for 1000 pF

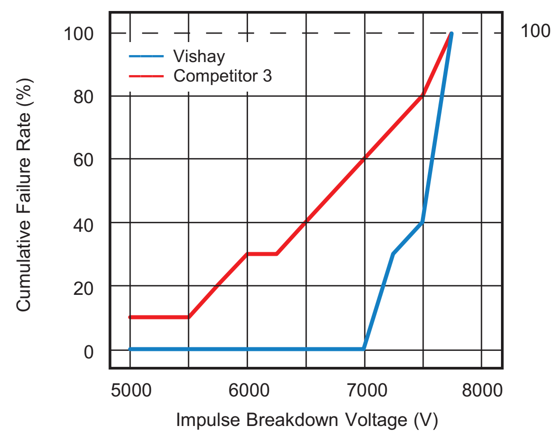

Fig. 2.3 - Impulse breakdown cumulative failures for 3300 pF

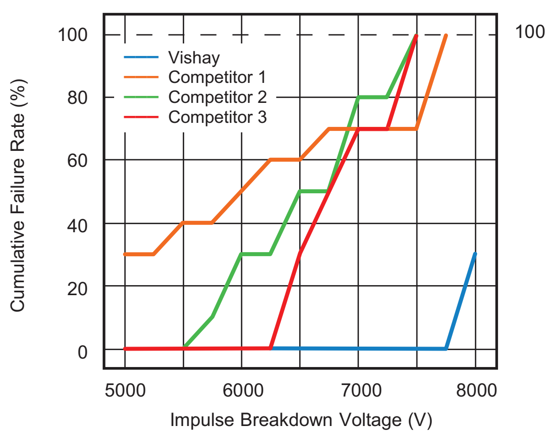

Fig. 2.2 - Impulse breakdown cumulative failures for 2200 pF

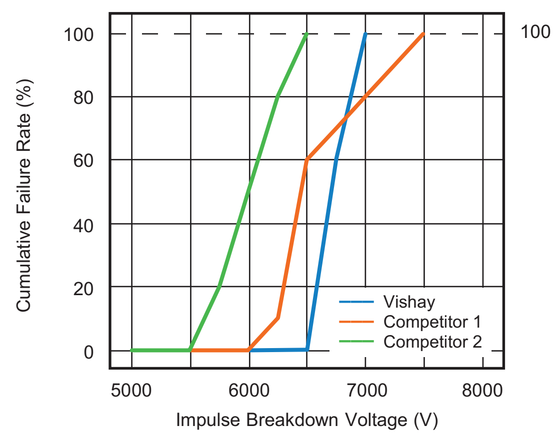

Fig. 2.4 - Impulse breakdown cumulative failures for 4700 pF

Figures 2.1 through 2.4 show a cumulative IBV for each capacitor tested. The cumulative failure provides more detail about each competitor's failure level.

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VOLTAGE COEFFICIENT OF CAPACITANCE (VCC)

The VCC effect and unbiased aging are specifically related to the ferroelectric nature of Class II MLCCs. VCC is a well-known characteristic in which applied bias influences ferroelectric domains and dipole alignment within the MLCC. This influence has a direct impact on the dielectric constant K of Equation 1.0, and thus proportionally to the MLCC capacitance value. [3] Other factors such as the manufacturer's material system, formulation, dopants, and internal design will also influence capacitance change.

Equation 1.0: $C = \varepsilon 0 \times A \times K \times N/d$

During the VCC test, a DC voltage is applied to the MLCC while monitoring the capacitance value. Voltage is increased incrementally from 0 V to 500 V. After some period of settling, the capacitance is recorded. Many types of Class II X7R capacitors will experience a capacitance loss with applied bias. VCC graphs of capacitance change vs. applied voltage are depicted in Fig. 3.0 through Fig. 3.3.

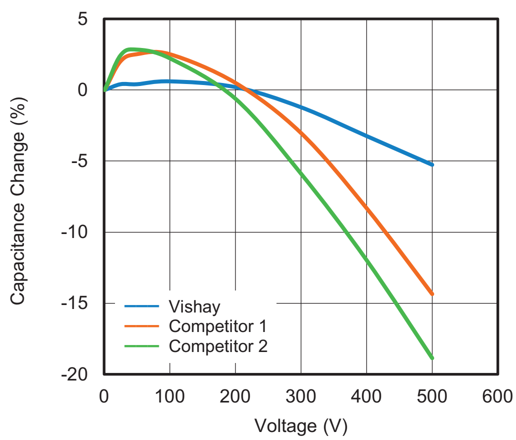

Fig. 3.0 - VCC for 2220, X7R, 1.0 nF safety capacitors from three manufacturers

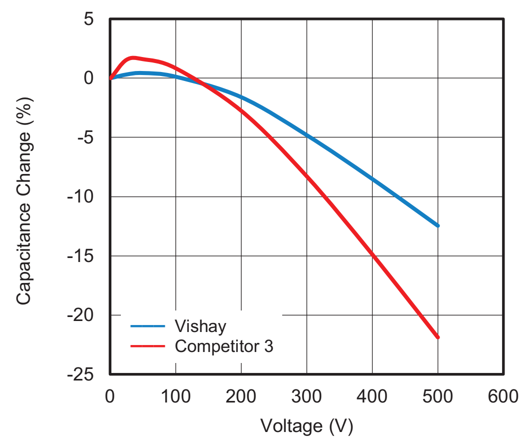

Fig. 3.2 - VCC for 2220, X7R, 3.3 nF safety capacitors from two manufacturers

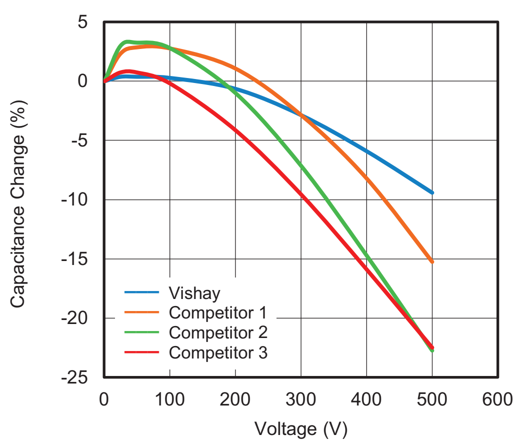

Fig. 3.1 - VCC for 2220, X7R, 2.2 nF safety capacitors from four manufacturers

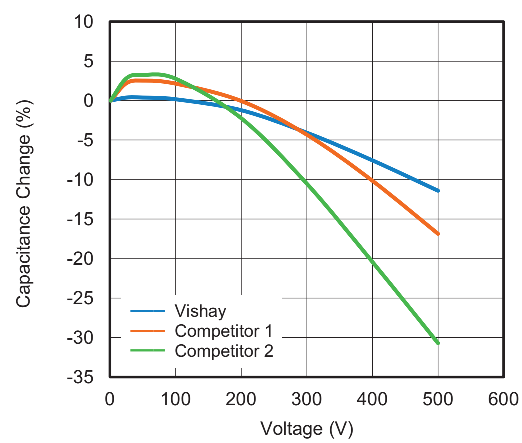

Fig. 3.3 - VCC for 2220, X7R, 4.7 nF safety capacitors from three manufacturers

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RESULTS OF VCC TESTING

Referring to Fig. 3.0 through Fig. 3.3, the Vishay MLCC tested had the least amount of loss and retained more capacitance with applied DC bias. Competitor 2's MLCC had the greatest loss for all capacitors tested: 2.5 to 3 times more lost capacitance compared to Vishay. Vishay's higher capacitance retention can be a crucial factor during all types of EMI and RFI transients. When these transients occur, harmful currents are diverted through capacitive decoupling and help suppress voltage fluctuations on the AC power supply line.

INSULATION RESISTANCE (IR) AT 25 °C TO 125 °C

A capacitor's IR is a resistive property that indicates how well the capacitor's dielectric system blocks or resists the flow of a DC current, commonly referred to as leakage current (I_L). It is common for a capacitor to have extremely high IR and resist the flow of leakage current. The IR units are expressed in MΩ or GΩ and are inversely proportional to capacitance. Most capacitor manufacturers will state IR at +25 °C is 1E11 Ω or 1000 ΩF, whichever is less. The ΩF unit often confuses users in how to determine the expected IR value. Simply put, IR = 1E11 Ω / µF. For values above 0.010 µF, the expected IR value will drop below 1E11 Ω. For all values below 0.010 µF, the IR value at 25 °C is expected to be a minimum of 1E11 Ω.

In this study all capacitors are less than 10 nF, so the minimum expected IR value is 1E11 Ω at 25 °C. Capacitor IR values are normally in the high giga-ohms and also follow Ohm's law per Equation 2. IR is also dependent on the capacitor dielectric material and previously mentioned properties of each manufacturer's design and formulation. The applied voltage and temperature can reduce IR and cause higher leakage currents to flow. The insulation resistance of each capacitor is measured with 500 V_{DC} applied, at 25 °C and again at 125 °C. The results of measurement results are presented in Table 3.0.

Equation 2: $IR = V/I_L$

RESULTS OF INSULATION RESISTANCE TESTING

TABLE 3: INSULATION RESISTANCE VALUES OF 2220 SAFETY CAPACITORS AT 25 °C AND 125 °C

CAPACITANCE (nF)	MANUFACTURER	TEMPERATURE 25 °C	TEMPERATURE 125 °C	RESISTANCE CHANGE (Ω)
1 nF	Vishay	1.15E12	3.47E12	2.31E12
	Competitor 1	5.98E11	6.88E10	-5.29E11
	Competitor 2	5.99E11	1.46E11	-4.53E11
2.2 nF	Vishay	6.06E11	1.58E12	9.78E11
	Competitor 1	2.94E11	2.70E10	-2.67E11
	Competitor 2	2.15E11	4.94E10	-1.65E11
	Competitor 3	4.69E11	1.61E11	-3.08E11
3.3 nF	Vishay	4.57E11	1.32E12	8.60E11
	Competitor 3	2.28E11	8.11E10	-1.47E11
4.7 nF	Vishay	2.83E11	6.66E11	3.83E11
	Competitor 1	1.25E11	1.28E10	-1.12E11
	Competitor 2	1.32E11	2.19E10	-1.10E11

Resistance values at 25 °C and 125 °C are presented in Table 3. All values tested exceed the required 25 °C IR limit of 1E11 Ω. Resistance change due to temperature is plotted in Figure 4.0. For all Vishay capacitance values, the IR increases as temperature rises, while competitors' IR decreases. These resistance changes at 125 °C are not significantly detrimental but Vishay's increase in IR at 125 °C can be desirable, as it correlates with a decrease in leakage current.

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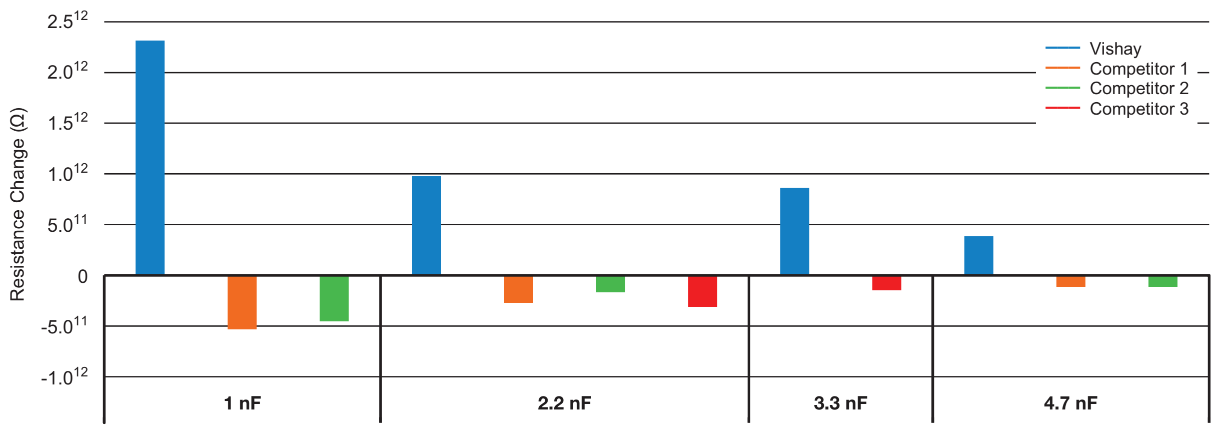

Fig. 4 - Vishay and Competitor Insulation Resistance Change From 25 °C to 125 °C

SUMMARY

The electrical characteristics of 2220 case size, 250 V rated, X7R, X1 / Y2 safety capacitors from Vishay and three competitors are compared using IEC 6038484-14 impulse, VCC, and IR vs. temperature testing. The results of all tests indicate advantages with Vishay safety capacitors.

- Most manufacturers met the 5 kV impulse level required of X1 / Y2, 250 V_{AC} rated safety capacitors. Extending the impulse magnitude above 5 kV, Vishay had superior impulse breakdown levels over all competitor parts tested. A high IBV ensures reliable operation and safety against harmful lightning surge transients, EMI, and RFI events
- Voltage coefficient data revealed that all Vishay capacitors retain more capacitance vs. competitor parts tested. High capacitance retention is desired for AC line transient suppression and voltage stability
- When tested at 500 V_{DC}, all Vishay capacitors had an increase in insulation resistance as temperature increased to 125 °C. All competitor capacitors had a drop in insulation resistance at 125 °C. Increasing insulation resistance vs. voltage at high temperature correlates with lower leakage current, dissipation factor, and power losses. Power distribution, telecommunications, and automotive applications are just some that benefit from high insulation resistance. Benefits include stable energy transmission, preventing cross talk, reliable data transmission, and withstanding harsh environments to ensure dependability in air, space, and automotive control systems

REFERENCES

[1] Safety Capacitors First: Class-X and Class-Y Capacitors, Nick Davis May 06,2019

[2] Fixed Capacitors for Use in Electronic Equipment - Part 14: Sectional Specification - Fixed Capacitors for Electromagnetic Interference Suppression and Connection to the Supply Mains, IEC 60384-14:2023

[3] Time-Dependent Capacitance Drift of X7R MLCCs Under Exposure to a Constant DC Bias Voltage, P. Coppens January 02, 2022, Passive Component Blog

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