Whitepaper

Durable reliable interference suppression with X- and Y- metallized film capacitor

Introduction

X- and Y- film capacitors are used to suppress interference of electronic devices, they are used in EMC filters which are externally mounted or directly employed on the circuit board. In addition, they protect the electronic device from excess voltage (transients) from the mains power and suppress the grid-bound retroactive effects of the electronic device on the supply network.

The number of electronic devices is rising steadily each year and this trend is gaining momentum. For example, conventional light bulbs are being replaced with electronically clocked energy saving lamps. In future, more and more residential buildings and factories will be illuminated by LED bulbs. Old street lamps containing mercury are being replaced with modern LED street lamps with electronic control boards. The phasing out of nuclear energy results in an ever increasing distribution of inverters, which convert the DC voltage gained from solar or wind energy into AC voltage. Energy Efficiency Legislation requires the use of electronically controlled motors and drives, such as electronically controlled heating pumps. More and more household appliances, for example, refrigerators and freezers are fitted with energy-saving electronics instead of mechanical controls. Modern induction cookers are finding their way into more and more kitchens. Electric and hybrid vehicles will be charged through the electricity grid in the years to come. The importance of applications from Smart Meters (intelligent electricity meters), Smart Home and Smart Grid sector will increase through the phase-out of nuclear power.

Only when all of these products which are connected to the grid stop interfering with one another will their smooth side-by-side functioning be guaranteed.

In the past, mainly linear power supplies were used to drive electronic devices. These linear controlled transformer power units did not cause high EMC loads due to their construction. As a consequence there were relatively few EMC-related interferences of electronic devices on the grid. That is why little attention was paid to the actual compliance with the EMC limits of an electronic device over its useful life. As long as there are no cases of interference, a device's electromagnetic compatibility (EMC) is then only measured in practice when the CE conformity is to be certified. This is the case before a manufacturer brings the device to market.

The EMC of an electronic device is, however, becoming increasingly the focus. This is because there are more and more electronic devices on the grid which require sufficient pwoer quality so that they function trouble-free and operate without disturbances. These include, e.g. many products from the Smart Meter, Smart Home and Smart Grid sector. With the Europe-wide roll-out of Smart Meters, tens of millions of devices will be installed which are dependent on a power quality with reliably limited interference voltages and currents in order to function error-free. It must be assumed that the responsible authorities shall identify the interference causers which disturb the device operations and be required to eliminate them.

This will mean that greater importance will be attached to the effective and reliable interference suppression of electronic devices over their entire useful life. That is why it is important that the useful life expectancy of the X- and Y- interference suppression capacitors used to suppress the interference is appropriate to that of the respective electronic device.

In contrast to aluminium electrolytic condensers, which are split into useful life categories (e.g. 85°C/2,000 hours, 105°C/10,000 hours), there is no such classification for film capacitors regarding their minimum life expectancy. This can mean that the same X- and Y- interference suppression capacitors are used in both low-cost consumer electronics as well as in the distinctly more sophisticated and more durable power electronics. However, this would only be acceptable if X- and Y- interference suppression capacitors were not subjected to any aging. This is not the case. Like all metallized film capacitors, they are subject to aging which is mainly determined by the factors temperature, voltage and humidity.

The aim of this whitepaper is to present an accelerated useful life test for X- and Y- filml capacitors (ALT-Test, Accelerated Life Test). The aging processes of the film capacitors which are to be expected during the entire life of the electronic device can be revealed with this test. The test considers all relevant factors which influence the aging of metallized fiml capacitors.

Using this Accelerated Life Test, the manufacturer of an electronic device should be able to ensure that the X- and Y- film capacitors intended for use possess an adequate life for the application. That is why it is recommended to include such an accelerated life test in the component qualification process.

Finite emission and immunity values of an electronic device according to the valid EMC limit curve values can be durably guaranteed only if the X- and Y- interference suppression capacitors reliably fulfil their specified function. Only then is the CE conformity of the electronic device over its entire life guaranteed.

Types of interference:

The following electromagnetic incompatibilities result from operating electronic devices:

Interference voltage (grid-bound emitted interference):

- Symmetric (differential) interferences
- Asymmetric (common mode) interferences

Interfering radiation (grid bound emitted interference):

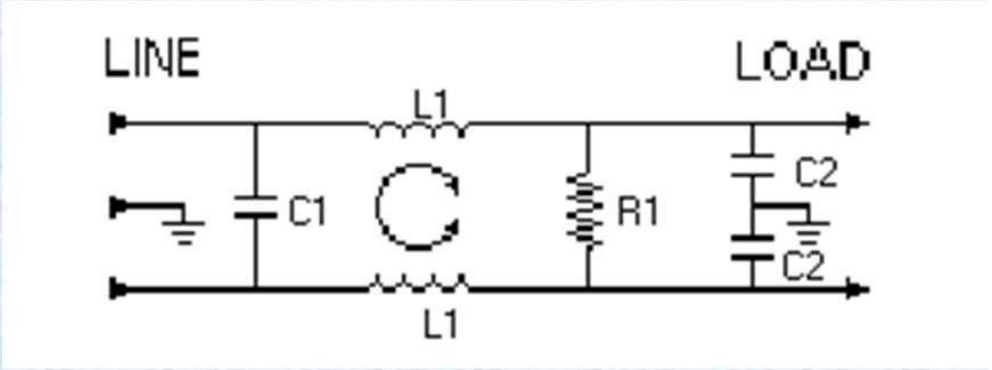
- Predominantly asymmetric interferences on line to or from the device which then act as "antennae".
- Emission from the device itself.

Before electronic devices are put on the market, they must certify their compliance with the respective limit curve values applicable for their device category e.g. the EN 55011_22, in order to prove their CE conformity.

Interference suppression though line filters - construction and function

Line filters are used in electronic devices to ensure that the valid EMC limit value curves are observed, regarding the maximum permissible immunity and emission values.

Typical constructions of line filters:



X capacitor (C1):

- between phase and neutral line or switched between two phases.
- dampens symmetric interferences (differential mode noise).
- shields high frequency interference signals from mass.
- shorts high frequency interference between the lines.

Y capacitor (C2):

- connected between phase or neutral line and device housing with contactable, protective earth (PE).
- dampens asymmetric interferences (common mode noise).
- shorts high frequency interference against earth.
- Leakage current must not be unduly raised.

Inductor (L1):

- For symmetric interference source (periodically opening or closing switch, e.g. Triac) and asymmetric interference source (e.g. oscillator for microprocessors).
- Increases the impendence of symmetric and asymmetric interference currents of the electric circuit.
- Reduces the interference currents caused by the harmonic currents and switching frequency.

<u>Test results of an accelerated life test of X2- and Y2- Film capacitors:</u>

The importance of a durable reliable functioning of X- and Y- interference suppression capacitors results from the configuration of a line filter.

However, commercially available X- and Y- film capacitors are subject to a susceptibility for uncontrolled capacitance losses due to climatic aging caused by undesired accumulating of humidity in the inside of the capacitor.

This, on the one hand, is proven by the associated failures when using X2 capacitors in capacitive power supplies. In this application an X2 capacitor is switched in series to the mains supply and is critical to the functioning of the application - in contrast to the "across the line” filter applications. Affected users report extreme cases where, already after one year, a large loss of capacitance (> 50%) of X- capacitors was determined which therefore resulted in failures in the field. A corrosion of the foil metallization of the X2 capacitors due to humidity was found to be the cause.

On the other hand, the susceptibility from such climatic aging due to humidity can be proven by a climate test with the parameters temperature, humidity and voltage.

In the following example, 10 X2- capacitors with 0.68µF and 305Vac of standard design from well-known manufacturers and the corresponding conventional 10 X2- capacitors of the humidity-robust THB version by HJC (THB-X2) were tested. The test conditions were 85°C, 85% RH and 240Vac for 1,000 hours.

The test was also performed with 10 Y2- capacitors with 0.001µF and 300Vac of standard design as well as with 10 corresponding Y2- capacitors of the humidity resistant THB version by HJC (THB-Y2).

The capacity values were measured at room temperature after a recovery time of 24 hours. The following images show the mean values of the change in capacity.

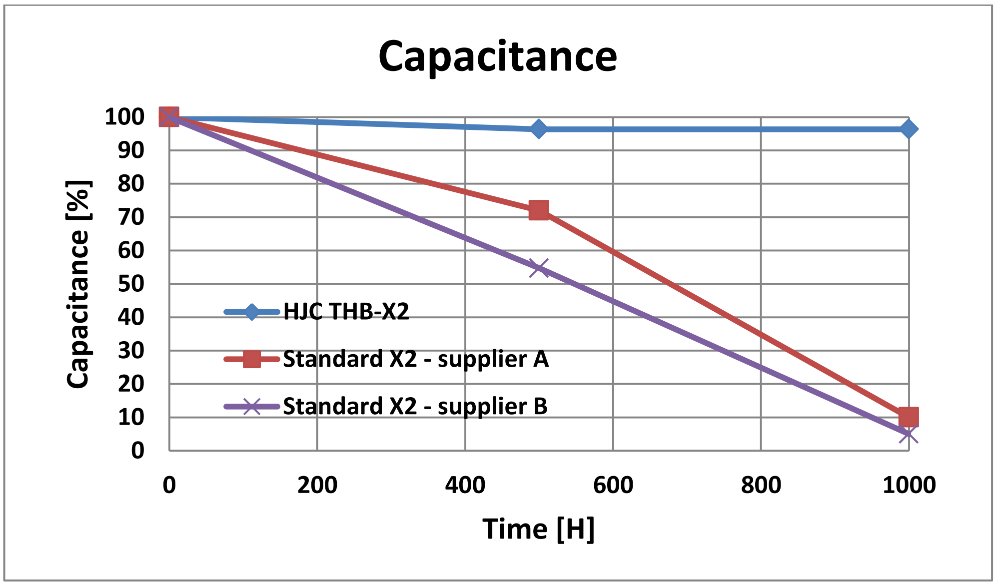


Image 1: THB-X2 capacitor type MKP-684K0305AB1221U by HJC (X2, 0,68µF/305Vac in THB version (humidity robust version)) and the corresponding standard X2 capacitors. Changes in capacity in a test with the continuous conditions 85°C temperature, 85% RH humidity and 240 Vac.

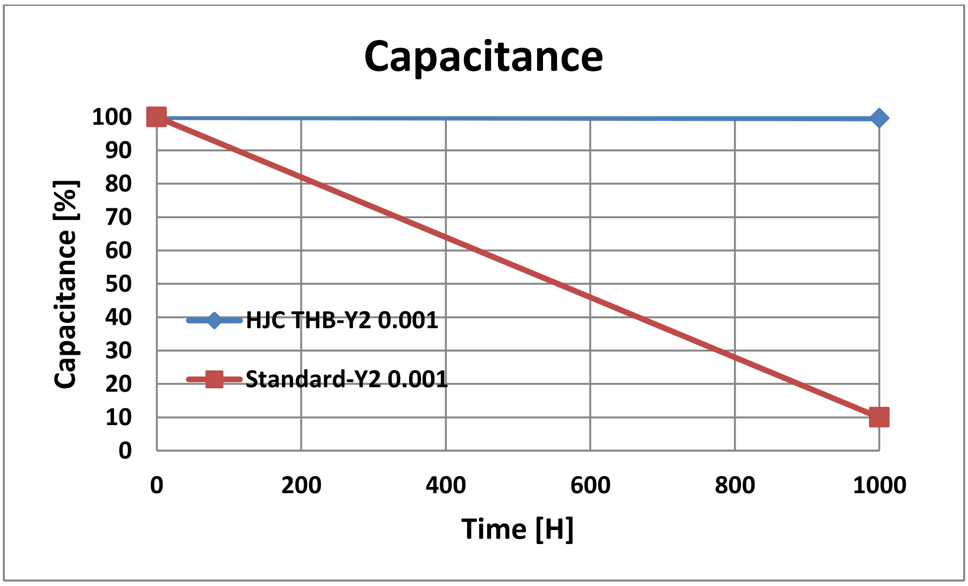


Image 2:THB-Y2 capacitor type Y2X1102K0300AB1101U by HJC (Y2, 0,001µF/300Vac in THB version (humidity robust version)) and the corresponding standard Y2 capacitors. Changes in capacity in a test with continuous conditions 85°C temperature, 85% RH humidity and 240 Vac.

The results prove that in practice there is a high risk of distinct losses in capacity with both standard X2- and also Y2- film capacitors when stress is simultaneously caused by temperature, humidity and voltage. Experience in the field shows that the respective effects can become apparent in practice even after a few years (< 2-3 years).

Causes of capacitance losses:

Construction of metallized foil capacitors:

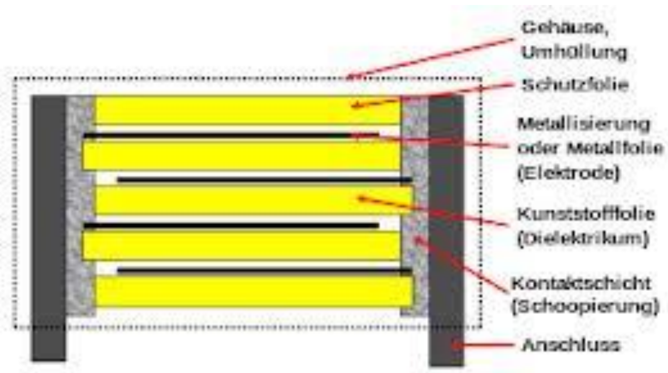


Image 3: Representation of the construction principle of a metallized film capacitor (Source: [http://de.wikipedia.org/wiki/Kunststoff-Folienkondensator)](http://de.wikipedia.org/wiki/Kunststoff-Folienkondensator)

Capacitance losses of a metallized film capacitor are caused by self-healing processes and by a reduction of the electrode metallization.

X- and Y- film capacitors are self-healing. High pulse-voltage in the mains can cause high pulse-currents in the capacitors. Due to the high locally concentrated current-density there will be a selective short circuit between the metallized electrodes with locally very high temperatures. The dielectric, and also the metallization layers which only have a thickness of about 0.02 to 0.05 µm, evaporates in the breakdown area. The cause of the short circuit is effectively burned away, whereby the resulting vapour pressure blows out the short circuit's electric arc. This process, which happens within microseconds, leads to an insulation area which deactivates the defective point.

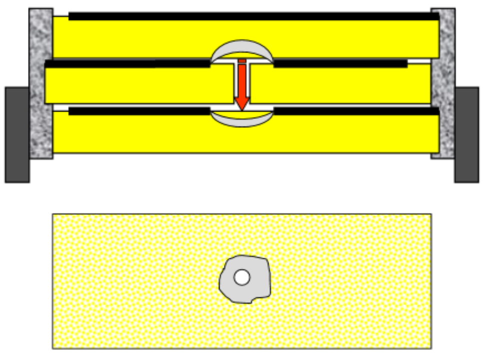


Image 4: Schematic representation of self-healing of a selective short circuit

(Source: [http://de.wikipedia.org/wiki/Kunststoff-Folienkondensator)](http://de.wikipedia.org/wiki/Kunststoff-Folienkondensator)

Self-healing corresponds to loss of electrode surface. Capacitance losses due a self-healing process are relatively small.

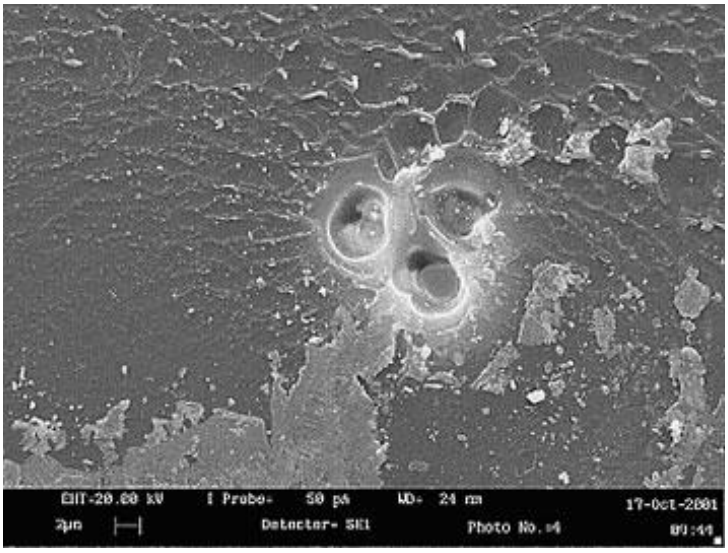


Image 5: Magnification of self-healing points in a polypropylene film (Source: http://www.era.co.uk/case-studies/failure-in-metallised-polypropylene-capacitors/)

In contrast, if severe losses of capacitance occur then they are mainly due to a corrosion of the foil metallization due to undesired humidity being present. During a corrosion process in the film metallization (zinc and/or aluminium), the metallization layer deteriorates leading to a thinning of the metallized layer. This process can result in a loss of electrode surface, with a corresponding loss in capacitance. The chemical processes of metallization occur faster when humidity and voltage are present.

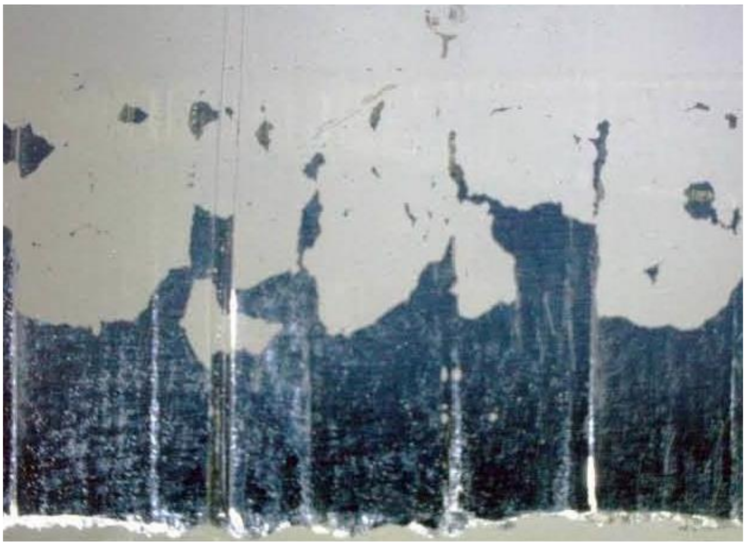


Image 6: Film metallization with severe corrosion.

If the impact of ambient humidity if severe, this can lead to a correspondingly high loss of electrode surface. This in turn leads to a correspondingly high, or even almost total, capacitance loss.

When moisture is present on the film metallization, the risk of a corrosion-related loss of electrode surface is higher, the thinner (high ohmic) the metallization layer. The electrodes then have less material to protect them from the corrosion process.

However, if the metallization layer is too thick, it impairs the self-healing process since the more energy is needed in the self-healing process the more metallization has to be locally insulated (evaporated). The high temperature which results from too much energy being expended can damage the plastic dielectric and, therefore, reduce its dielectric strength.

When manufacturing metallized film capacitors with long life expectancies, it is therefore a matter of principle to select the best possible compromise for the dielectric and the electrode metallization. The compromise must respect the required breakdown voltage, pulse strength and robustness against climatic aging, whilst retaining the self-healing features.

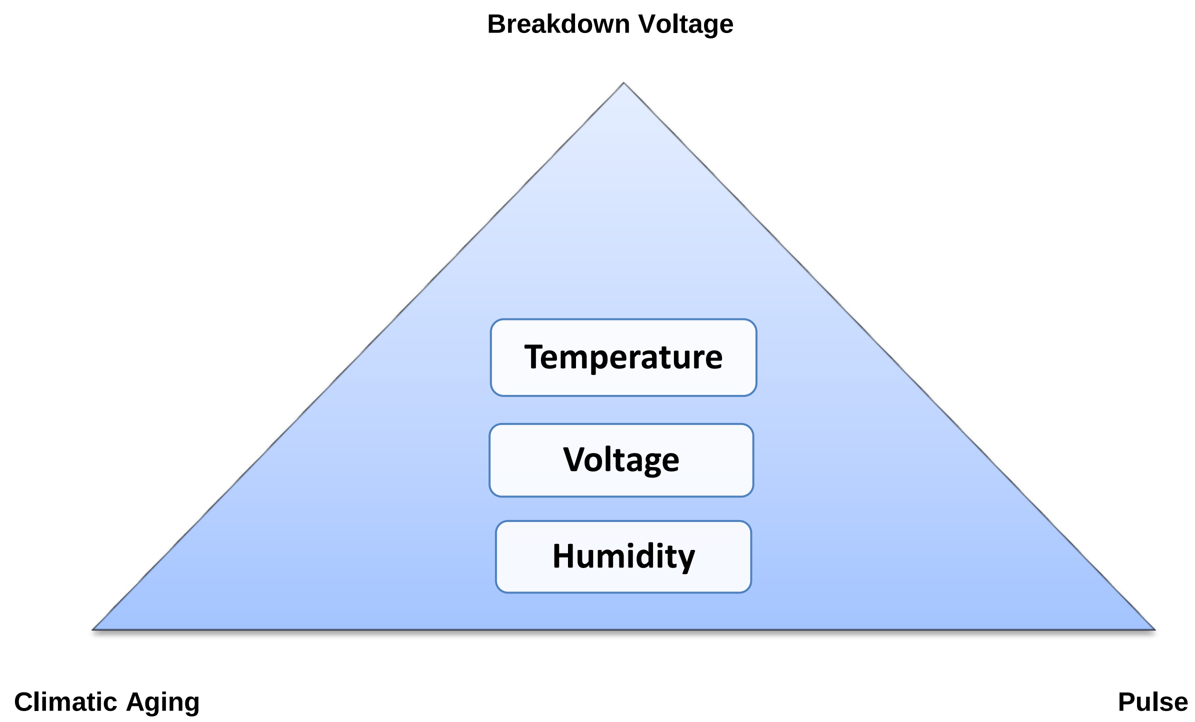


Image 7: Determining factors of the life of an metallized film capacitor

Focusing on only one goal can jeopardize the others as each goal requires a different approach in the selection of the most suitable thicknesses of dielectric and metallization. The breakdown voltage e.g. needs a thin electrode, whereas pulse and climatic robustness requires a thick electrode. That is why designing a metallized film capacitor always requires a compromise which satisfies all goals.

Current IEC standard

The Standard IEC 60384-14 defines all tests with which the application suitability and the conformity with the latest standard for X- and Y- capacitors must be proven. This Standard also includes a test to check the humidity resistance of a capacitor. However, this test does not correspond to operational conditions, since it is only performed with the parameters temperature and humidity, but without voltage. However, mains voltage is permanently applied to X- and Y- noise suppression capacitors in a line filter on the AC side.

Current IEC Standard in terms of humidity resistance:

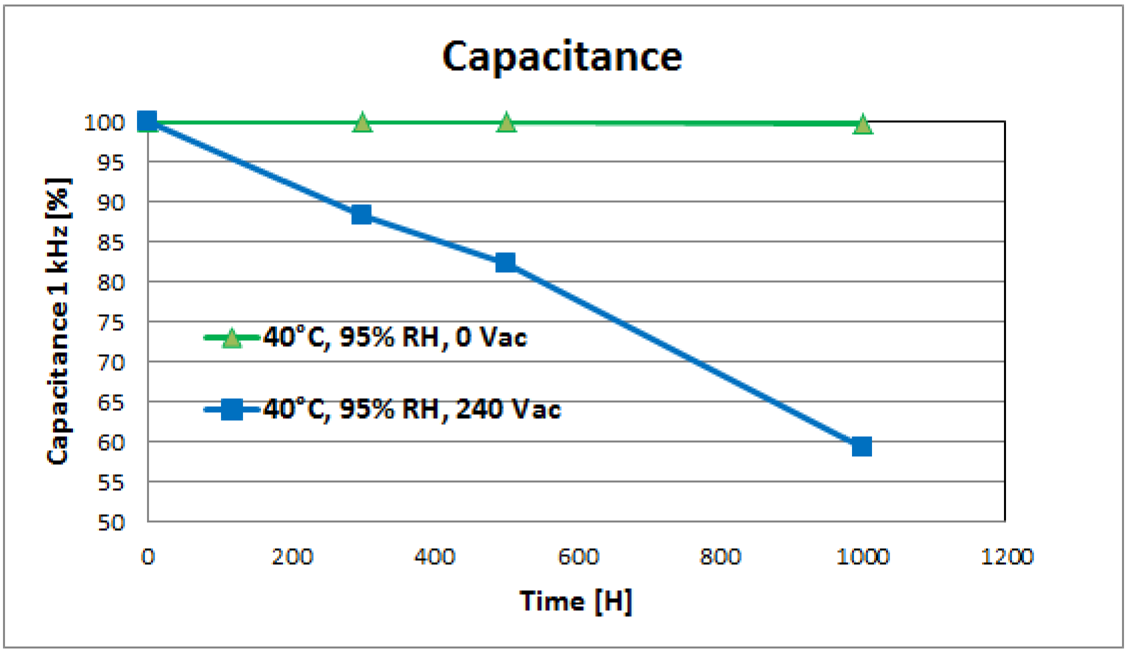
X- and Y- noise suppression capacitors:

IEC 60384-14 4.12 (damp heat)

➔ 40°C, 90-95% humidity, at least 21 days

➔ without voltage!

However, the chemical process of corrosion in the metallization occurs faster when humidity and voltage are present at the same time. So it can be determined that a humidity resistance of X- and Y- Film capacitors cannot be satisfactorily proven using the Standard IEC 60384-14 4.12 (damp heat test) since the test is performed without voltage.



Picture 8: Mean values of the capacitance-loss over the time

<u>Green curve:</u> Standard X2-capacitors from HJC in accordance with the latest issue of IEC 60384-14, testet with the conditions of point 4.12 of the IEC-norm (40°C/95% RH).
<u>Blue curve</u>: Standard X2-capacitors from HJC in accordance with the latest issue of IEC 60384-14, testet with the conditions of point 4.12 of the IEC-Norm plus voltage (40°C/95% RH, 240Vac).

All X2-capacitors shown in picture 8 are specified with a capacitance-tolerance of +/- 10%. The test-result shows that a conventional X2-capacitor can pass the test 4.2 (damp heat test) from the latest issue of the standard IEC 60384-14 with very good results (green curve). However, the same capacitor may exceed his specified capacitance-value already after about 250 hours (blue curve), if in addition to the temperature of 40°C and Humidity of 95% there will be also applied the mains-voltage.

HJC has made the same testings with numerous equivalent series from the competition. All of them are specified according to the latest issue of the IEC 60384-14. The strong difference in the capacitance-drift when a capacitor is tested with 40°C/90% RH without voltage and when it is tested with 40°C/90% RH with voltage can be recognized.

This conditions of 40°C, 90% RH and applied voltage can not be considered as being unrealistic. Depending on the place of installation (e.g. on the ceiling in an electronic ballast) and on the climatic season this conditions can appear even in indoor-applications. In across-the-line applications for EMI-suppression a X2-capacitro is permanently loaded with AC-voltage. Therefore a meaningful test must always include voltage (bias).

By means of appropriate tests it can be easily understood that the combination of "temperature & humidity & voltage" found in practice can lead to a faster aging process and a higher loss in capacity than the combination of only "temperature & humidity" or "temperature & voltage".

An explanation of why the current IEC Standard prescribes a humidity resistance test without voltage can perhaps be that the Standard was created many years ago. Subsequently, the tightening of the humidity resistance criterion could have been neglected in association with the cost-saving trends and the use of ever thinner metallized films (keyword miniaturization). This made it possible to use increasingly thinner metallized films, without violating the criteria of dielectric strength and pulse strength applicable to X- and Y- noise suppression capacitors. However, this trend was made at the expense of the climatic robustness.

It can be determined that the robustness of X- and Y- Filmcapacitors against humidity can't be observed in a satisfying way with meeting the criteria of the latest IEC 60384-14. Since the test 4.12 (damp heat test) is only specified to apply temperature and humidity, but no voltage, this test can be considered just as a storage-test, but not as an operational test.

The accelerated life test for X- and Y- film capacitors proposed by HJC:

HJC has found proof that the ambient humidity impairs the long-term functionality of metallized film capacitors. Likewise, there are quality defects which occurred in X2-film capacitors in the field which are clearly a result of the influence of undesired humidity inside the capacitor. Whether this humidity entered the capacitor during the production-process or whether it penetrated the capacitor from the outside is hard to verify.

In order to draw the necessary conclusions from these incidents HJC has introduced two important measures to increase the robustness against climatic aging and so also the life expectancy of the X2- and Y2- film capacitors:

- the introduction of a new design for X2- and Y2- film capacitors using materials with low water diffusion rates combined with an increased steam diffusion path and the expansion of diffusion barriers. Important building blocks are, besides the suitable metallized films, the capacitor housing and the potting compound, as well as a production process under appropriately controlled climate conditions.

- the introduction of tightened test conditions in order to verify the suitability of a capacitor to remain uninfluenced by a humid environment.

The studies performed in the test laboratory at HJC have shown that it is necessary to combine the three influencing factors temperature, humidity and voltage in order to test the long-term robustness of a capacitor construction against climatic aging.

Whether a sufficiently humidity-robust version of the X- and Y- film capacitors was selected and whether this capacitors have been produced without the inclusion of humidity during the manufacturing-process can be proven by using an accelerated life test with the following parameters:

- **85°C, 85% humidity, 240Vac, 1000 hours.**

This test is often called the THB test (Temperature, Humidity, Bias) or 85/85 test. Bias being the English term for constant voltage. Instead of the "85/85 test", this test should rather be termed the "85/85 test with voltage" in order to rule out any misinterpretation.

The following criteria apply to pass the test:

- $\Delta C/C \leq 10\%$
- $\Delta \tan\delta / \tan\delta \leq 200\%$ at 1 kHz, as well as at 10 kHz or 100 kHz. The loss factor at these frequencies may only maximally increase by a factor of 3.
- Insulation resistance ≥ 50% of the initial value.

The measurement of the tan δ at a higher frequency than 1 kHz, e.g. at 10 kHz or at 100 kHz, is performed in order to verify the corrosion resistance of the metal spray contacts.

An X- or a Y- capacitor has reached its end of life if it does not meet one of these criteria either during its use in the application or in the accelerated life test. The end of life is described as the point in time from when the capacitor does not fulfil its specified values.

According to the application, the following criteria could also be defined as permissible; shorter test duration, higher capacity loss or a greater increase of tan δ during the intended useful life. It must be considered here that the increase of tan δ (ESR) is directly proportional to the increase in capacity loss and to the rise in temperature of the capacitor. If the selected criteria for passing the test are too large, there is the risk that the permissible more vigorous aging process will take on uncontrollable dynamic dimensions.

Example of a suitable interpretation of tan δ in a test chart:

Nr	1	KHz Cs		tan δ	10 KHz		IR	
	Initial (μF)	After Test (μF)	△C / C	Initial (10^{-4})	After Test (10^{-4})	△tan δ /tan δ	Initial (GΩ)	After Test (GΩ)
1	60.36	60.83	0.78 %	117.0	162.0	38.5 %	1.25	0.64
2	60.58	60.74	0.26 %	117.0	149.0	27.4 %	1.25	0.22
3	60.38	59.66	-1.19%	120.0	154.0	28.3 %	1.32	0.54
$\bar{X}$	60.44	60.41	0.05 %	118.0	155.0	31.4 %	1.273	0.47
MAX	60.58	60.83	-0.41%	120.0	162.0	35.0 %	1.320	0.64
MIN	60.36	59.66	1.16 %	117.0	149.0	27.4 %	1.250	0.22
R	0.12	0.65	-435.18%	1.73	2.56	47.8 %	0.04	0.22

In order to be able to interpret tan δ unambiguously, tan δ should be given in [E-4]. According to the underlying criteria, a maximally 3-fold increase of tan δ is permitted during the test. If a specification is given in [E-4], it is easy to understand whether this criterion was met in contrast to a specification in [1] or in [%].

It may cause confusion when [%].is used for units of [1] or for units of ratio.

Since tan δ is already a ratio (imaginary over real impedance), the best way to make the difference is to use:

a) tan δ: [10-4]
b) Δ tan δ / tan δ: [%]
c) Δ tan δ: [10-4]

This test with 85°C, 85% humidity and voltage for 1,000 hours has already been used for many years in the qualifying processes of semi-conductors.

This test is already performed by other film capacitor manufacturers besides HJC, especially in Japan.

Leading manufacturers of Smart Meters have started to include this THB test (85/85 with voltage) in the qualifying processes of metallized film capacitors after X2-capacitors suffered an increase in failures in the field which could be traced back to climatic aging. By passing this test, the users can conclude that the tested capacitors will have a life expectancy of 20 years in their application according to the Hallberg-Peck calculation model.

Meanwhile there are also automotive manufacturers who test a fully assembled circuit board in a THB test. Though this test, the users first became aware of the susceptibility of metallized film capacitors for accelerated climatic aging when humidity and voltage are present.

The conventional X2- and Y2- noise suppression capacitors by HJC comply with the current IEC Standard 60384-14 and do not pass this THB test. Comparative measurements with other manufacturers as well as studies conducted by customers verify that this is the case with the comparable products of the majority of the competitors.

Tested standard X1- film capacitors also do not pass this test with 85°C, 85% RH and 240Vac.

In contrast, the humidity-robust capacitors of the THB-X2 and the THB-Y2 series by HJC pass this THB-test with very good results. Thus they make an important contribution to the consistent maintenance of the original form of the insertion attenuation curve of an electronic device as to its durable CE conformity.

The importance of robust endspray-contacts:

For the life expectancy of metallized fllm capacitors the robustness of the endspray-contacts and a humidity- robust metallization that permits self-healing plays an important role.

Metallized film capacitors possess the ability to withstand high voltage- or current-impulses. This means that all constructive parts of a film capacitor must be able to tolerate the occurring peak current up to a permissible internal temperature increase. Here the contact areas of the endspray with the electrodes can be viewed as the limitation of the current carrying capability (ampacity). Ultimately these contacts consist of many punctiform contacts which represent a critical area of the capacitor's internal resistance. Through current flow, heat is generated particularly at these contact points which can locally lead to high temperatures and lead to the contact burning off (http://de.wikipedia.org/wiki/Kunststoff-Folienkondensator).

In addition, the metallic endspray contacts are stressed by climatic aging when corrosion of the contact metallization (e.g. zinc, tin, aluminium) occurs.

In the application the X- and Y- noise suppression capacitors can be stressed by high dV/dt impulses from the supply network (mains). According to the capacitance of the capacitor, these dV/dt impulses lead to high current impulses through the capacitor:

Current i(t) = C·dV/dt.

So a voltage impulse in the mains with 100V/µsec leads in an X2- capacitor with 1µF to a current impulse of approx. 100A/µsec. However, the strength of voltage-impulses in the mains s increasingly steadily due to the steadily increasing number of non-linear consumers.

The more the punctiform endspray contacts have been already damaged due to climatic aging caused by corrosion the less they are able to survive the heat generated by such high current impulses. If the endspray contacts lose their current carrying capability because of this damages, the ESR increases accordingly. The ESR increase is directly proportional to the increase in power-loss and to the rise in temperature of the capacitor. This is why endspray-contacts must possess a high robustness against corrosion and high current impulses, so as not to be able to cause an uncontrolled increase of the ESR.

For these reasons, it is important to test the corrosion resistance of the endspray-contacts. This can be done by measuring the tan δ at a higher frequency than 1 kHz, e.g. at 10 kHz or at 100 kHz. Likewise the impulse voltage test (surge-voltage test) described under item 4.13 in the IEC 60384 must be passed *after* the THB test (85/85 test with voltage).

When the self-healing processes are fully and properly functional and when the layers of films are well compressed, the current impulses within microseconds only cause small and isolated defects in the electrode metallization and in the dielectric, which result in a relatively small loss in capacitance and increase of the loss factor.

If the film-layers are not well compressed, this could result in gaps between the layers which are filled with air. When this airgaps are ionized, there can occur corona- discharges. Corona-discharges, same as corrosion by humidity, can lead to a local demetallization of the electrodes with the corresponding capacitance-loss. Voltage-impulses in the mains can ignite the process of corona-or glow discharge, the process will be maintained by the mains voltage. Corona-discharges can only appear in capacitors which are not well compressed, therefore enabling airgaps between the film layers.

In a THB-test (85/85-test with voltage) a capacitor proves whether the winded film layers are well compressed without airgaps. Otherwise in this accelerated lifetime-test there would show up capacitance-losses from corona-discharges. If the DUT (device under test) pass a THB-test with good results, it proves its robustness against climatic aging as well as against corona-discharges.

High energy densities in a selfhealing process and in the endpspray-contacts are the root-cause of changes. The electrode reduction through humidity-corrosion tightens the conditions, so that once the processes have started, they are accelerated.

<u>Importance of the correct capacitor design for its fail-safe behaviour and the operational safety of the end device:</u>

There are reports on the Internet of cases where the steel housing of a PV inverter was ripped apart during operations. It described how this was caused by capacitors on the AC side, which had released gases into the inverter housing. These gases then accumulated there until they ignited explosively.

The reason for the fault with these capacitors is to be found in an improperly functioning self-healing process!

A very high local energy density occurs inside the capacitor for the duration of the self-healing process at the affected areas of the electrode and dielectric. This results in a very high temperature for a short time at this spot, which extinguishes as soon as the defective area has been insulated. However, if this self-healing process is not fully completed, this temperature cannot be extinguished and it can cause damage to the neighbouring fiml layers in a kind of avalanche effect. During this process a gas mixture can be released due to the carbonization of the plastic dielectric. In extreme cases this gas mixture can lead to gas pressure and explosive vaporization. In order to rule out this safety hazard, it is very important that the self-healing processes function properly and completely.

Self-healing processes cannot be successfully completed if the metallization is too thick.

This fact must absolutely be taken into account when determining the criteria for passing the THB test (85/85 with voltage). The criteria must ensure that a high robustness of the capacitor against climatic aging and also properly functioning self-healing processes can be verified. Both goals can contradict one another. For, in order to achieve a climatic robustness, the capacitor manufacturer might have selected a metallization which is too thick. This would then jeopardize the self-healing properties of the capacitor.

A thick metallization can thus set more material against the corrosion process. On the other hand, more energy would have to be expended for self-healing in order to vaporize the metallization. The self-healing processes cannot be successfully completed if the metallization is too thick. The generation of energy would then not be halted. If this process then does result in a outgassing this can in turn jeopardize the operational safety of the end device.

A degassing inside the capacitor can occur when the capacitor heats up higher than the thermal pyrolysis temperature of the plastic dielectric during operations. For polyester this is at approx. 235°C and for polypropylene at approx. 220°C.

For this reason, it is important to observe not only the change in capacity during a THB test. For reasons of operation safety, it is equally important to verify the increase of the loss factor tan δ according to the described criteria. Only when the increase of the tan δ remains under control during overload, can an uncontrolled increase of ESR and capacity loss - which would cause a uncontrolled increase in capacitor temperature - not occur.

The failure mode of the capacitor must have a fail-safe feature. This means that the capacitor can never become so hot during operations as to cause a degassing. This is guaranteed when the capacitor is dimensioned correctly according to its application load and life expectancy and its self-healing property functions properly. This must be verified using the correctly defined criteria for passing the THB test (85/85 with voltage).

Possible effects of climatic aging or failure of interference suppression capacitors:

For X2 film capacitors:

- Continuous until almost complete capacity loss.
- On failure they become high resistive and hang in the circuit without a function.
- Ripple currents can then no longer be short-circuited.
- Since the symmetric branch can no longer be loaded, the ripple currents look for new paths.
- Asymmetries occur if the symmetrical dissipation to N is no longer given.
- Asymmetric interferences becomes larger.

➔ ***Deterioration of EMC!***

For Y film capacitors:

- Continuous until almost complete capacity loss.
- On failure they become high resistive and hang in the circuit without a function.

- The interferences remain on the symmetrical branch since the asymmetric dissipation towards earth is no longer possible.
- Asymmetric interferences looks for its own path over other dissipation possibilities leading to widespread distribution (e.g. over housing).
- Interference voltage and field strength increase.

➔ ***Deterioration of EMC!***

Capacitive leakage currents result from high common mode leakage currents. When the capacitance of a Y capacitor decreases, the leakage current decreases. This is, however, not constructive since the asymmetric interference portions are meant to be dissipated by the Y capacitor.

If X- and Y- capacitors age or fail, the risk of saturation in current-compensated EMC inductors increases:

- Leakage currents are common mode currents.
- Leakage currents cause the magnetizing of current-compensated inductors.
- The inductor does not function when saturated.
- If the inductor is in saturation, it produces harmonic wave components and becomes interference.
- Additional harmonic wave components cause losses, resulting in additional capacity loss of the device.
- The mains inlet filter can become interference if the inductor is in saturation.

Ripple current distribution in switch-mode electronic devices with internal X-capacitor, e.g. PV inverter:

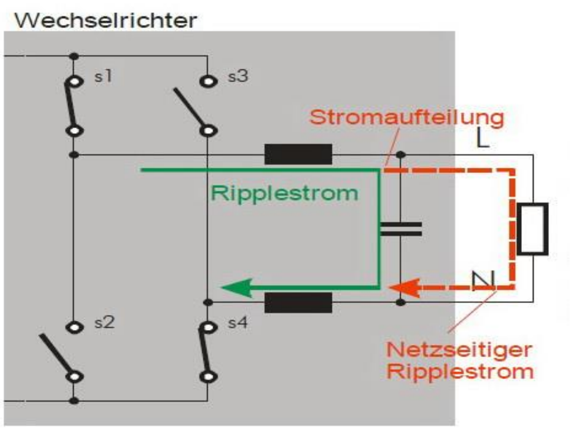


Image 9: Ripple current distribution between electronic device using an X capacitor and the mains in a low impedance grid.

(Source:http://www.iwes.fraunhofer.de/de/publikationen/uebersicht/2011/emv-unvertraeglichkeitenzwischenelektrizitaetszaehlernundstromr.pdf)

At low grid impedance:

> Ripple current distribution with an internal X capacitor between device-side ripple current and mains-side ripple current.

However at strong aging or failure of the X- capacitor***:***

The mains-side ripple current may increase!!

IEC-standards for EMI don't specify ripple-currents. Threshold values for emitted interference (AC) are defined for the frequency range 0 Hz to 2 kHz in the specific basic standards. The high frequency emitted interferences are normatively limited between 150 kHz and 30 MHz. However, the EMC behaviour in the frequency gap between 3 kHz and 150 kHz in the specific basic standards and the majority of product family standards has not yet been regulated. However, the frequency of most switching power supplies, inverters, electronic ballast, clocked power electronics etc. lies in this normatively unregulated frequency range between 3 kHz and 150 kHz. The switching frequency and its harmonic from these electronic devices causes differential mode ripple currents. In connection with the X capacitor in the electronic device such mains-sided ripple-currents often only appear in low impedance grids due to the characteristics of the voltage sources of the internal interference source.

Due to the characteristics of the voltage sources of the internal interference sources of such an electronic device, some devices pass the classic EMC standard in the artificial mains network and still produce high interference currents in low impedance grids.

(Source: "EMV 2010, Grenzwertlücke – Wechselrichter stört Elektrizitätszähler, Jörg Kirchhof, Fraunhofer IWES" [EMC 12010, Threshold value gap – inverter interferes with electricity meter, Jörg Kirchhof, Fraunhofer IWES]).

In the electronic device, the ripple current is split between the internal X capacitor and a low mains impedance. However, in most cases the user is not aware of an inacceptable aging or a failure of the X- capacitor, since a severe aging or a failure of the X- capacitor in a mains parallel "across-the-line" application is not critical for the functioning of the end device. The electronic device continues to operate on the mains, however, without the X- capacitor fulfilling its function. The result in a low mains impedance is that the mains-side ripple currents actually increase during the remaining operating time of the electronic device!

An X- capacitor at the mains inlet represents not only the gate from the mains into the electronic circuit, but also the gate from the circuit to the mains. A severe aging or a failure of the X- capacitor leads to a corresponding increase of the EMC values of the electronic device as well as to an increase of the mains-side ripple currents.

These ripple currents increase, the more such electronic devices are connected to the grid and the more these devices are operated despite severe aging or the failure of an X- capacitor. These can have serious consequences, such as e.g. the reduction of the useful life of other electronic devices without sufficient immunity connected to the mains or it can impact the reading precision of electronic electricity meters.

Humidity can destabilize the whole capacitor-sytem:

The presence of undesired humidity inside the capacitor can destabilize the whole system of a metallized Filmcapacitor. Major implications of such a humidity inside the capacitor can be:

Loss of capacitance:

- Selfhealings around dielectric breakdown (Humidity may accelerate the effect).

- Humidity-corrosion of the electrodes.

- Corona-discharges (Humidity promote it for lower electrical field).

Increase of loss-factor tan δ:

- (climatic) aging of the dielectric (U,T).

- humidity-corrosion in the metallization.

- humidity-corrosion in the endspray-contacts.

- complete break-off of the endspray-contacts (Humidity can be involved).

Undesired humidity may be implicated into the filmcapacitor already during its manufacturing-process. Furthermore, humidity can ingress into the capacitor during the application if the encapsulation (housing and potting) of the capacitor is not sufficiently tight.

As descripted, the presence of humidiy inside the capacitor can have severe consequences to the reliability of X- and Y- Filmcapacitors. However, the current IEC-standard specifies an insufficient damp heat test. Moreover, the failure of X- and Y- capacitors in EMI-filter applications is not critical for the functioning of the end device. Therefore in many cases, the only focus from manufacturer and customers is on miniaturization and cost-down, as long as the current IEC-standard has been satisfied. In order to assure that the same rules are valid for all market-participants, the IEC-60384 should be updated in the point 4.12 (damp heat) according to the latest findings as soon as possible.

Conclusion

The effective suppression of interference of an electronic device over its entire useful life is becoming increasingly important, also with regard to its emissions, as well as its immunity. Otherwise there will be no seamless coexistence of the increasing number of electronic devices on the grid.

If the electronic circuit functions reliably according to its specifications, then the EMC represents the sole potential risk for a quality complaint by the customer during the entire useful life of the electronic circuit.

The stable observance of the specified capacitance values of the X- and Y- noise suppression capacitors is of major importance for a durable interference suppression of an end product over its entire useful life. However, laboratory test and field failures verify their susceptibility to climatic aging due to humidity influences.

A loss in capacity of the X- and Y- capacitors has consequences for the electromagnetic compatibility (EMC) of an electronic device. There is the risk that the interference limit value curves are no longer observed and so the CE conformity of the device no longer exists.

In addition, a failure or a strong aging of X- capacitors may increase the mains-side ripple currents in a low impedance grid. This can have a negative impact on the life and the function of other electronic devices connected to the mains.

Therefore, it is important for manufacturers of electronic devices that the X- and Y- noise suppression capacitors used reliably fulfil their specified properties over the entire life of the end product.

Metallized film capacitors stand out from other capacitor types due to their numerous technical advantages. These include e.g. a low loss factor, a low dependence of the capacity and loss factor on temperature and frequency, a high current carrying capability, they are suitable for alternating and direct current. Moreover, they possess a high dielectric strength and impulse loading capacity and are available in high capacity values. Because of their self-healing properties they are well suited to handle even high pulse-voltages in the mains without significant capacitance-losses.

However, metallized film capacitors are not static components. Same like many other electronic components, they are subject to aging processes. That is why it is important that the users ensures the useful life expectancy of the X- and Y- noise suppression capacitors intended for use are appropriate to that of the electronic end device. The affected customers performed root-cause analyses on noise suppression capacitors which failed in the field prematurely showed clearly that the main reason for field failures was due to a climatic aging of the film metallization.

The current Standard 60384-14 for noise suppression capacitors proved to be inadequate to reliably test the climatic robustness of a capacitor in the application. In item 4.12 the simultaneous combination of the application parameters actually present in practice is not considered for testing the humidity resistance. This test can be considered as a storage-test, but not as an operational test. According to the findings of affected customers the current risk is too large to find an inadequate capacitance stability of conventional X- and Y- noise suppression capacitors after a few years in the application, although these capacitors comply with the currently valid Standard IEC 60384-14.

Since a significant capacitance-loss or a failure of X- and Y- capacitors is not critical for the functioning of the electronic device, often even contrary to better knowledge X- and Y- capacitors with an insufficient life expectancy are being used, as long as they are fulfilling the standard IEC 60384-14. This attitude doesn’t cope with the key role of a X-capacitor as the gate between the mains and the electronic circuitry.

The actual importance attached to the reliable functioning of a X- and Y- noise suppression capacitor over the entire useful life of the electronic device must again be given higher priority. Responsible manufacturers of electronic devices are well advised not to wait on the review of the Standard Norm IEC 60384-14 4.12. They should only to use X- and Y- noise suppression capacitors, which have a proven and sufficient robustness against the simultaneous loading of temperature, humidity and voltage. In addition, they must have a properly functioning self-healing in case of overloading and a fail-safe feature.

A suitable test (THB test, 85/85 test with voltage) was presented in this whitepaper for testing the climatic robustness under consideration of the self-healing properties of the X- and Y- noise suppression capacitors intended for use. Based on the stability of the capacitance during the test, this test also provides information on the robustness of the capacitors against corona-discharges.

Electronic devices are now made with life expectancy of 50,000 to 200,000 hours. The manufacturer of such devices should include the accelerated life test presented here in their own components qualification process as part of the quality assurance of the end products. By fulfilling the test criteria, the X- and Y- noise suppression capacitors prove their suitability to achieve the same useful life as the inductors in filter applications. The emission and immunity of the electronic device will then be reliably assured for its entire useful life, without the risc that impermissible rippled currents could be feed into the mains during the operation of the device.

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Note:

All shown test results are based on tests which have been conducted in the laboratory of HJC. The results prove the relevance of the discussed topic, but don't claim an universal validity for all film capacitors in the market. Everyone who doubts the results may conduct his own tests. In this case, HJC recommends to apply the same test- conditions and – criteria. Thus, the results will be commonly comparable. Furthermore, it will be avoided that there will be various different testing methods in the market. In fact, this will contribute to the creation of one common standard for all market participants for an accelerated lifetime-test of metallized film capacitors.