

# Factors determining the production testing of high reliability interference suppressor capacitors

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**Abstract-** Non-linearity and noise properties of a capacitor have been established as criteria for selection of interference suppressor capacitors for different reliability classes. It can improve the process of quality estimation of high reliability capacitors. The implementation of techniques for non-linearity and noise measurements in the system for production testing of high reliability interference suppressor capacitors is described. Selected experimental results of measurements for capacitors produced by MIFLEX have been presented.

## I. Introduction

Appropriate standards demand quality and reliability tests for interference suppressor capacitors during their production. Reliability tests are usually carried out using environmental trials. However they can not be applied in production testing due to their long duration and destructive nature. Additionally, accelerated tests do not give the accurate evaluation of their work in normal work conditions. A simple, non-destructive and fast approach is needed for reliability estimation.

The problem of reliability testing for capacitors can be solved by application of the production testing system realizing additionally non-linearity or/and noise measurements. It was considered appropriate to include measurements of both non-linearity and 1/f noise in the same programme because not only has a dependence between these two parameters identified in the case of other fixed elements, but also an explanation for the observed dependence on, for example, geometrical factors, has been found to apply with the similar success to the two magnitudes. The proper choice of third harmonic (TH) index, noise parameter (method and electrical circumstances of their measurement) and rules of classification into reliability group gives a possibility to predict individually reliability of tested capacitors [1].

## II. Physical, exploratory and noise properties of foil interference suppressor capacitors

Interference suppression capacitors are designed to attenuate the radio frequency interferences generated by household equipment and conducted to supply networks. The capacitors WXP-224K X2 **0,22**  $\mu\text{F}$  10% 275 V~, WYP-683M Y2 **0,068**  $\mu\text{F}$  20% 275 V~ and WXPC-334M X2 **0,33**  $\mu\text{F}$  20% 275 V~ (Fig. 1) produced by MIFLEX [2] were investigated.

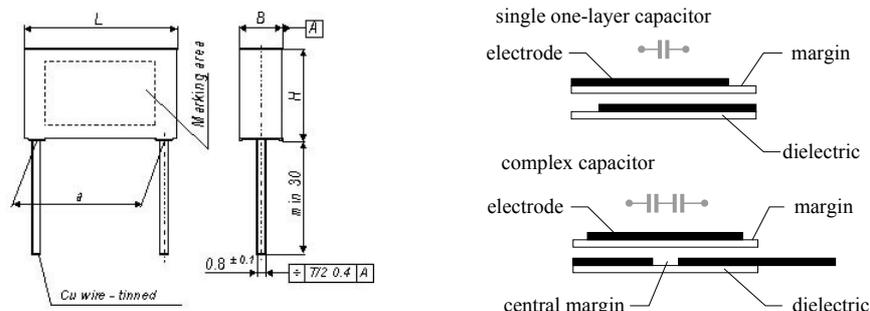


Fig. 1. The measured interference suppressor capacitors type WXP 0.68  $\mu\text{F}$ /250V

In capacitors there are thermal noise sources referred to losses and  $1/f$  noise sources dependent on a technology of their production and circumstances of their operation. Noise equivalent circuit of a capacitor  $C$  in the low-frequency range is shown in Fig. 2 [3], where  $G_{nt}(f)$  - power spectral density of shunting resistance  $R_s$  (conductance  $G_s$ ), respectively, including resistance of isolation and losses in a dielectric,  $G_{nf}(f)$  - power spectral density of  $1/f$  noise source.



Figure 2. Noise equivalent circuit of a capacitor with two noise (series and parallel) sources

The basic causes of capacitor failures are: improper silver adhesion (flicker of capacitance about 0.001% of a mean value –  $1/f$  noise), inhomogeneities and microcracks of foil ( $1/f$  noise), electrodes and dielectric heterogeneity, higher temperature of plates, improper terminal construction (impulse, burst noise), silver migration, dielectric aging.

### III. System for production testing of high reliability capacitors

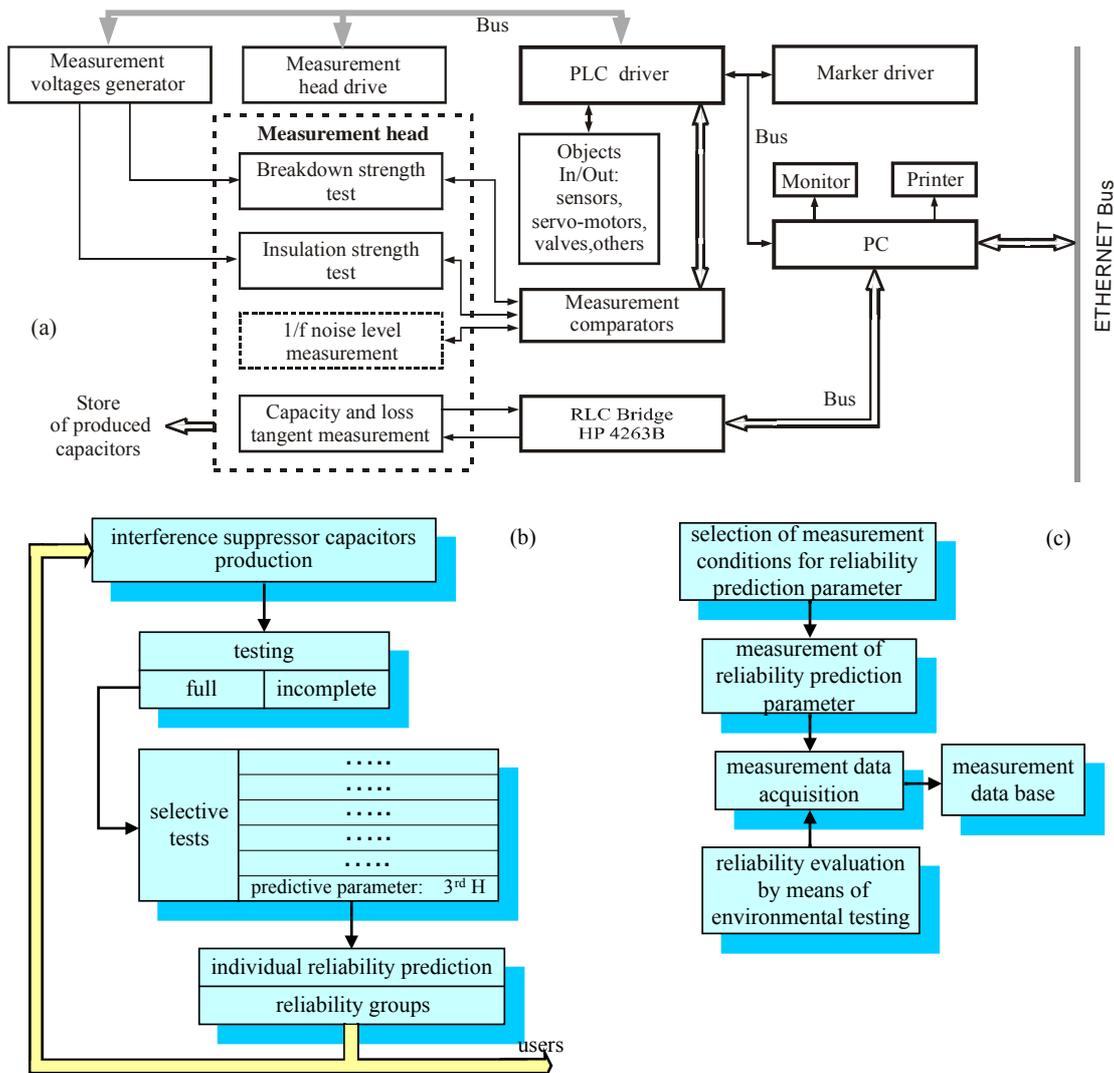


Fig. 3. The system for interference suppressor capacitors testing during manufacturing

To assure a high flexibility of manufacturing and cooperation with a general management organization in the quality domain the system for testing capacitor parameters and classification of tested items should fulfil high functional requirements with possibilities of its easy reconfiguration and further development. The additional task of capacitor reliability testing can be solved in the production testing system - Fig.3 (a) [4], by performing non-linearity or/and noise measurements - Fig. 3 (b). The appropriate choice of TH index (3<sup>rd</sup> H), noise parameters (method and electrical circumstances of their measurement) and rules of classification into reliability group gives a possibility to predict individually reliability of an every tested capacitor - Fig. 3 (c).

#### IV. Nonlinearity measurement

Non-linearity measurements consist in determining the deviation from linear V-I characteristics. Therefore the TH is proportional to the extent of elementary non-linearity. Three basic components of non-linearity can be distinguished:

- Built-in (additive) present within any device; its level is to be considered as a non-linearity mean value. The higher this component, the more difficult the detection of the unwanted excessive non-linearity.
- Unwanted (excessive) additive; may be the same origin as the built-in (taking into account the physical origin). It makes the U-I characteristic deviate from its linear shape and is equal zero at no defect present. It appears due to high contact resistance of any junction affecting the shape of the U-I curve, physical properties of the base material, defects and inhomogeneities in the material structure or interaction with the environment.
- Unstable in the time domain; non-linearity is often temperature dependent and due to the heating up can change significantly in the time domain.

If the first harmonic amplitude increases, the response of the modulated signal will grow allowing to distinguish the built-in from the unwanted non-linearity components.

The non-linearity of capacitor under test (CUT) is determined by a measurement of TH (30 kHz) generated by a capacitor when a 10 kHz signal is applied to it. The TH component is chosen as a measure of the non-linearity of the capacitor impedance  $Z_x$ . Principle of the TH measurement is shown in Fig. 4.

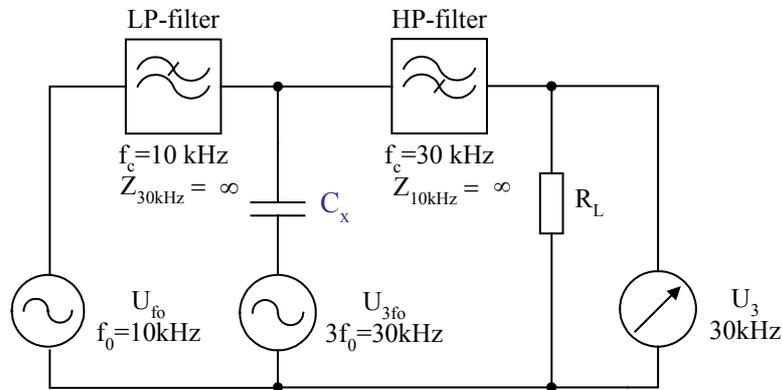


Figure 4. Simplified diagram of the TH measurement

The third harmonic current is equivalent to a no-load voltage  $U_{3f_0}$  in series with the CUT having an impedance  $Z_x$ :

$$U_{3f_0} = U_3 \left( 1 + \frac{|Z_x|}{R_L} \right), \quad (1)$$

where the third harmonic voltage  $U_3$  is measured over the load impedance  $R_L$ . By means of the matching transformer it should be ensured that the available power could be supplied to CUT throughout of a wide impedance range.

The foil capacitors normally exhibits low distortion, therefore reliability testing by means of the TH measurement can be carried out with success. It can be proved that TH is dependent on the signal rms value by the third order and on the second order of the foil thickness. Therefore the dependence of the foil thickness is a good tool to find capacitors with weak spots. In case of polystyrene capacitors the utmost stability is required and it is fulfilled at the TH measurement.

The TH level of several batches of MIFLEX WXP-224K X2 10% 275 V~ capacitor [2] samples (100 pieces each) was measured using two different kinds of device linearity testers.

The Component Linearity Test Equipment LCT 10 (Danbridge) [5] measures the third harmonic of the CUT and it can determine whether to reject the capacitor on the basis of the measurement result. The level of measured TH can be below  $-160$  dB and the absolute value of the capacitor impedance can be less than  $100 \Omega$  to more than  $3 \text{ M}\Omega$  supplying the  $10\text{kHz}$  voltage up to  $1 \text{ kV}$  and  $4\text{VA}$  with the efficiency of more than 30 capacitors/s. The programmable controlled measurements are carried out through the IEEE 488 or RS-232 C interface with programmable rejection limits.

The Device Linearity Tester LTC 10100 (VS Technology) [6] enables the self-adjusting amplitude of a driving signal from  $0.01$  to  $10 \text{ V}$  giving the DC bias from  $0.1$  to  $10 \text{ V}$  for the absolute value of capacitor impedance from  $10 \text{ m}\Omega$  TO  $100 \Omega$  with the same efficiency as LCT 10 by the IEEE 488 interface. It also enables the evaluation of non-linearity variations in the time domain. The application card of the LTC 10100 is intended for foil or plate based capacitors in capacity range from  $1 \text{ pF}$  to  $100 \text{ mF}$  with maximum power load  $12 \text{ VA}$ . It enables to detect poor contacts between foil and lead-in wire, defects in dielectrics and evaluate the quality of a base material.

The TH value of components (stemming from the same batch) with nominally the same impedance should have the Gaussian distribution around the mean value. However, usually a few of components exhibit a higher level of TH due to defects or deviations in material composition (Fig. 5). Exposing the batch to an accelerated life trial, the components having a higher value of TH will also be prone to exhibit inferior reliability. However, high-dielectric capacitors have sometimes excessive TH from a small defect hidden in the high inherent distortion which cannot be easily detected. In such cases it is used to plot the TH values on a special probability chart. The actual value of TH in a good component should be found experimentally.

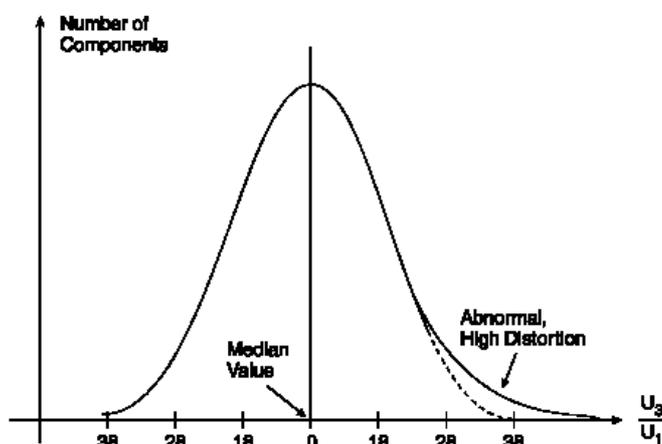


Figure 5. Typical TH distribution in a batch of capacitors

The actual statistical distribution of the third harmonic level within the selected populations of identical-capacitance samples (stemming from the same batch) in a semilog representation which highlights small-value relative deviations is shown in Fig. 6.

The main part of an every curve represents the range of built-in non linearity adequate for good quality devices. On the left side of these areas we have a range corresponding to none or minimal non linearity whereas on the right side is the range of unwanted, excessive non linearity referring to the capacitors with lower level of reliability.

The analysis of the achieved results confirmed the relation that if the value of capacitance increases the mean value of TH distribution for every batch also increases. The TH index is dependent on the capacitance of tested interference suppressor capacitors. The shape of the TH distribution is very important as a basis for the criterion of capacitors classification on the reliability classes.

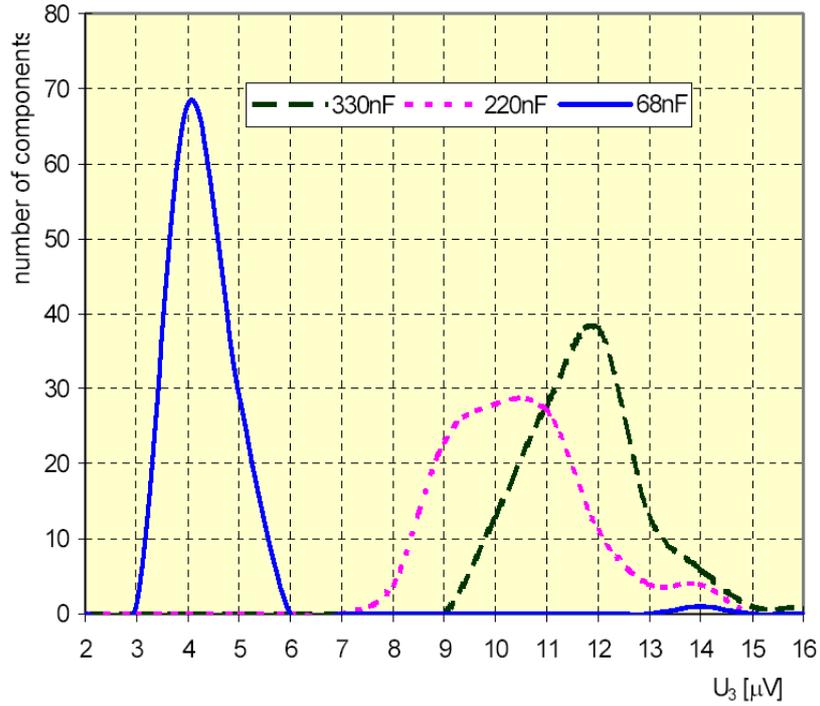


Figure 6. Statistical distribution of the TH for single batches of foil capacitors

## V. Noise measurement

Low-frequency noise measurements require special instrumentation, appropriate conditions of capacitor polarisation and adequate time for averaging of measured noise waveforms. For this reason they could be realised in the system for batches of samples from the whole population of produced elements. The current noise spectral density at the chosen frequencies divided by a square of the current is proposed as a quality indicator. It could be measured directly after a DC polarisation of tested component. However this procedure requires high DC voltage for capacitor biasing before the measurement and is time consuming.

We propose to use only AC large-signal stimulation of the tested capacitor without DC polarisation. In that case the  $1/\Delta f$  noise ( $1/f$  noise amplitude modulated by a large-signal carrier), also proportional to the square of the current, can be measured in the frequency band near the carrier frequency. The frequency conversion of flicker noise to the upper sideband of the carrier frequency has a frequency and amplitude dependence. However, in that case there are heavy requirements on data acquisition system due to very high level of AC stimulation signal comparing to measured  $1/f$  noise.

The modification of the measurement procedure (Fig. 7) relies on noise measurements in the low frequency band after filtration of AC stimulus signal. The level of the signal at the filter output is now much lower and requires very careful amplification in the low noise preamplifier but it does not contain the very strong AC stimulus signal.

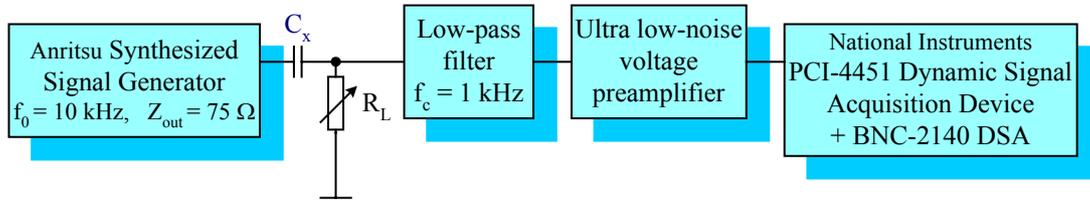


Figure 7. Block diagram of the  $1/f$  noise measurement without DC polarisation

The PCI-4451 Dynamic Signal Acquisition Device enables 16-bit resolution and can sample the noise signal at software-programmable rates (at LabVIEW control) from 5 to 204.8 kS/s in 190.7  $\mu$ S/s increments using programmable gain amplifier from  $-20$  to  $60$  dB in  $10$  dB steps. The input has both analog and real-time digital filters implemented in hardware to prevent aliasing. Digital antialiasing

filters automatically adjust their cut-off frequency to remove frequency components above half the programmed sampling rate. It causes a delay of 42 conversion periods between the input analog and digitized data. 128-times oversampling, delta-sigma modulating ADCs gives the low noise and low distortion of the PCI-4451. Accurate shielding of the measurement site proved useful.

The specification of the  $1/\Delta f$  noise measurement results will be published in the separate paper.

## VI. Conclusion

Accomplished investigations enable to state that the increased level of TH and noise is mainly caused by:

- instability of contacts,
- improper adhesion,
- electrodes and dielectric heterogeneity,
- weak contact between an electrode and a terminal,
- ferric oxide existence in dielectric particles,
- slow processes of insulating layer degradation
- mechanical instability of a capacitor.

The idea of quality and reliability control by non-linearity and noise testing and has been already proved for other electronic components [7-10]. The implementation of techniques for non-linearity and noise measurements in the system for production testing of high reliability interference suppressor capacitors gives a possibility of individual testing of an every produced element for accepted criteria of testing and classification.

Additionally, selected batches of capacitors could be additionally tested by means of the acoustic emission signal analysis and the partial discharge method [11].

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