MINIATURISATION OF SURFACE MOUNTED

MULTILAYER CERAMIC CAPACITORS

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SUMMARY:

This paper presents the extensive work EUROFARAD has been conducting for several years in order to miniaturize the multilayer ceramic capacitors suitable for space use. The aim of this miniaturization was naturally to:

- develop components corresponding to the low voltages of many modern applications
- reduce the size of the ceramic capacitors and, as a consequence, the size and weight of the pieces of equipment

The paper details hereunder the key points of this research, key points which cover mainly:

- Materials selected (for dielectrics, internal electrodes and terminations)
- Design rules (with a particular emphasis on ceramic layer thickness, margins, covers…)
- Process steps (both at manufacturing level and controls stages) to guarantee the reliability of thin ceramic layers (down to 6µm for 2C1/2R1 and 8µm for NPO)
- Mechanical compatibility of the ceramic parts with the mounting board taking into account the mounting process (reflow and iron soldering) also the technical routes which have been explored as well as the results obtained. An explanation will be proposed for the most surprising ones.

At last we describe the new developments we are dealing with and give some hope for more miniaturization.

BACKGROUND OF THE WORK :

Modern electronic pieces of equipment are generally digital. So the voltages involved are quite low. Looking at 5 years in the past one could notice the lower rated voltages allowed in ceramic capacitors QPL was 25 Volts whereas the pieces of equipment used typically 5 Volts or less.

As a consequence there was a big demand to lower the rated voltage of the capacitors because lowering the rated voltage is generally achieved by decreasing the dielectric thickness what implies increasing the capacitance value as it is linked to the inverse of the dielectric thickness.

So, EUROFARAD decided to reach such a miniaturization by a combination of 3 factors:

- decreasing the dielectric thickness of the ceramic layers what means creating 16 Volts rated parts
- developing a new smaller size (0603) as the smaller size available in QPL was 0805 and that most of 0805 25V capacitance values can be achieved in 0603 16V parts

- evaluating flexible termination technology. The initial reason of such an evaluation is that decreasing sensitivity of parts to thermo-mechanical stress. It's known that flexible terminations allow to lower this sensitivity

DEVELOPMENT OF 0603 AND 16 VOLTS RATED PARTS

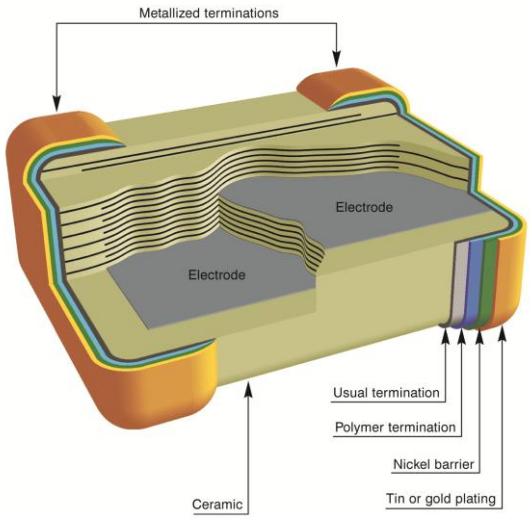
MAIN PARAMETERS

These 2 developments have been combined, i.e. we have developed a smaller size (0603) with rated voltages of 16,25, 50 and 100Volts as well as we have extended the 0805 to 2220 (25 to 100 Volts) ranges by adding them 16 Volts ranges.

- Decrease of the dielectric thickness. As already explained, when the thickness of the ceramic dielectric decreases, the capacitance value increases. So, it's clear that miniaturization and lower rated voltages are linked to the ability to manufacture thin dielectric layers able to pass the classical tests of ESCC23400 and 3009. Casting and manipulating thin dielectric layers, typically around 10 µm is not an easy task and to reach such a result EUROFARAD had to design, settle and install a new manufacturing line which allows :
    - to cast high quality grade thin dielectric layers. This has been possible through the development of new slurries formulations and through casting on a plastic carrier in a clean environment. Dielectric sheets with a thickness of less than 10µm – what is very small for PME technology- have been manufactured and used in capacitors manufacturing
    - not to manipulate the ceramic sheets until they are stacked into a bar. The plastic web used for casting is also used as a carrier during the printing (roll to roll printing) and stacking steps. The web is separated from the ceramic only after each individual layer has been stacked on the bar under construction

  In addition it has been noted that some ceramic are not suited for the manufacturing of parts with a very low dielectric thickness. The 2 main reasons for this conclusion are :
    - a quite big increase of the dissipation factor
    - the impossibility to get defect free parts. Generally the very low voltage rated parts show delaminations or cracks. The high fire dielectrics, probably because of the differences in firing shrinkages of the ceramic and electrode (metal) seem to be more prone to this kind of defects and, so, have not been selected for the lowest voltages
- Smaller size (0603). Let's remember the smallest ceramic capacitor size available in EPPL and QPL was 0805. The development of lower rated voltage (typically 16V) was making possible to get, for example, the 100nF 25V 0805 capacitance value in 0603size with a rated voltage of 16V. As, for small sizes, the dimensions of the lateral margins have a big impact on the active surface and, as a consequence, on the available capacitance values, we paid attention to the quality of the stack in order to reduce the margins as much as possible and get the highest capacitances
- Flexible termination technology. Let's remember that this technology is well-known and widely used in multilayer ceramic capacitors manufacturing. Its main point is that the classical silver basic termination is over-coated by a conductive polymer (silver dispersed into epoxy) and that the nickel barrier and solder layer are electroplated over this conductive "plastic". This gives the part's terminations some flexibility which allows the capacitors to be more resilient when facing high mechanical or electromechanical stresses. We present next page a schematic drawing of such a termination

The ability of this technology to space applications has been demonstrated through mechanical tests (500 thermal shocks and 100 thermal shocks + 85/85 humidity test) and the traditional life-time tests (classical or accelerated) without forgetting to take into account the mounting technology (iron soldering or reflow soldering) and the board material



Flexible termination drawing

The results have been very good, and the main conclusions are:

- the flexible layer helps the parts to withstand high thermo-mechanical stresses without cracking
- the electrical performances are not affected by these stresses or by long electrical and environmental stresses
- low voltage parts have a better reliability when manufactured using the flexible terminations technology than when they have classical terminations. This result is, somewhere, quite surprising and we had to understand why.

TESTS PROGRAMS FOR THE EVALUATION AND QUALIFICATION OF 0603 TO 2220 16V TO 100V RANGES

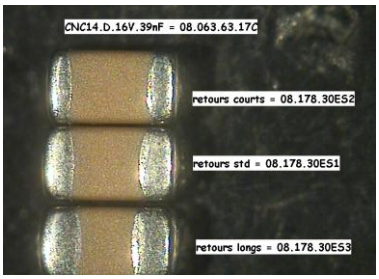
These programs have been based on ESCC23400 (for evaluation) and ESCC3009 (for qualification) with some amendments to take into accounts the specificities of these ranges. More particularly a test composed of 100 thermal shocks (-55°C to +125°C) followed by a 85°C/85% humidity/1,5V 1000 hours has been added This test was aimed at pointing, if any, the failures due to micro-cracking during mounting which allow silver migration and lead to insulation resistance decrease and/or short circuits.

Besides this “classical” approach which aims at proving and measuring the performances and reliability of the “capacitors only”, we have conducted many tests to check the compatibility of these components with the usual mounting methods and boards’ materials (mainly alumina and glass/epoxy such as High Tg FR4)

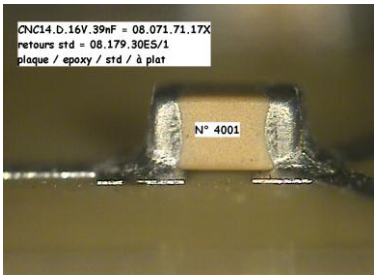
Tests description

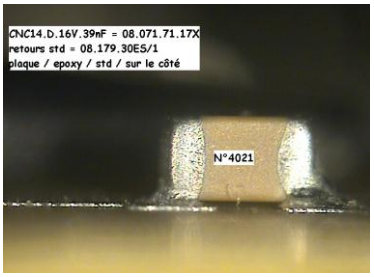
0603.16V.39nF and 2220.100V.1µF parts have been mounted different ways:

- Different band ends length

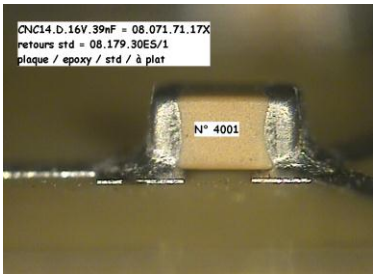


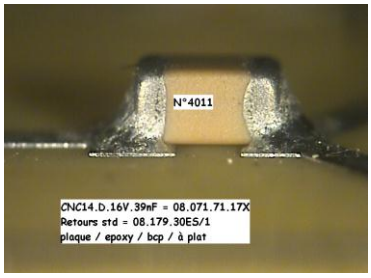
- Mounting direction (for 0603 only) :





- Soldering paste quantity : standard // more





- Mounting substrates nature and design :

- Alumina (AgPd pads) // high Tg epoxy (SnPb plated pads)

- Redesigned mounting substrates (both materials) to optimize the fitting between pads and parts

- Sn60-Pb40 soldering paste reflow method :

Hot plate // vapor phase // iron hand reflow

=> A few defect occurred, mainly on :

- long band ends (contravenes the more efficient substrate design)
- excessive quantity of paste
- on iron hand soldering for 2220

Role of flexible termination on reliability : extended range feasibility

Following previous tests, we chose the best compromise (standard band ends length, standard paste quantity, high Tg epoxy mounting substrates, hot plate reflow) to test a range extension of 0603-2220 16-100V ; we also compare classical termination (silver / nickel electroplating / Sn60-Pb40 electroplating) and flexible version (silver / flexible overlayer* / nickel electroplating / Sn60-Pb40 electroplating).

* : silver charged epoxy termination.

Test vehicles were CNC12.16V.1µF and 0603.16V.100nF.

Test performed on these extended range parts were :

- Temperature (up to 170°C) and voltage (up to 5.5Un) step-stresses

Model	CNC12.16V.1µF		CNC14.16V.100nF	
Termination	Standard termination	CerUflex termination	Standard termination	CerUflex termination
V final step-stress (5.5Un)	80% OK	80% OK	90% OK	100% OK
T° final step-stress (170°C)	90% OK	100% OK	100% OK	100% OK

- Thermomechanical tests (thermal shocks and damp heat test)

Model	CNC12.16V.1µF		CNC14.16V.100nF	
Termination	Standard termination	CerUflex termination	Standard termination	CerUflex termination
Thermal shocks (500 cycles)	90% OK	**100% OK**	80% OK	**100% OK**
Damp heat (100 cycles + 1000h)	40% OK	**100% OK**	0% OK	**90% OK**

- Life-tests (125°C/4000h) under 2Un and 4Un

Model	CNC12.16V.1µF		CNC14.16V.100nF	
Termination	Standard termination	CerUflex termination	Standard termination	CerUflex termination
LT 2Un (4000h)	85% OK	**100% OK**	95% OK	**100% OK**
LT 4Un (4000h))	80% OK	90% OK	90% OK	100% OK

The tests have demonstrated that the flexible termination technology has a positive role on reliability

- because of its thermo-mechanical stresses relief action, what was our hope when beginning this work
- but also on the life test results (for the lowest voltages and smallest size). This result is more surprising and analysis have been conducted to find the root cause of this result. The main difference observed after conducting a destructive physical analysis on

- parts without flexible termination
- parts with flexible termination

is that when the polymer layer is not present, some nickel ingress can be observed on the defective parts. So, as the defects on parts without the flexible termination can't be linked to cracks, it's assumed that the polymer layer prevents the chemicals of the plating bathes to penetrate through the termination - which is never fully dense – and etch the ceramic through the combined action of time and temperature.

CONCLUSION ON THE DEVELOPMENT OF 0603 AND 16 VOLTS RATED PARTS

The ranges proposed 5 years ago for evaluation, i.e.

- 0603 size capacitors (rated 16 to 100 Volts)
- 16 Volts rated parts (from size 0603 to size 2220).

proved to be very reliable (both NPO and 2C1/2R1)

In addition, the use of a flexible termination allowed extending ranges, in particular for the lowest rated voltages

All these new offers are described in QPL list.

DEVELOPMENT OF 0402 AND 10 VOLTS RATED PARTS

Because of these very encouraging results, Eurofarad decided to go further. To answer the user's needs, which ask now for an extension of the qualified ranges (see above), EUROFARAD is now (still for NPO and 2C1/2R1 capacitors), working on the development of:

- A smaller size (0402)
- Lower rated parts. It has been chosen 10 Volts rated ranges (from size 0402 to size 1210).
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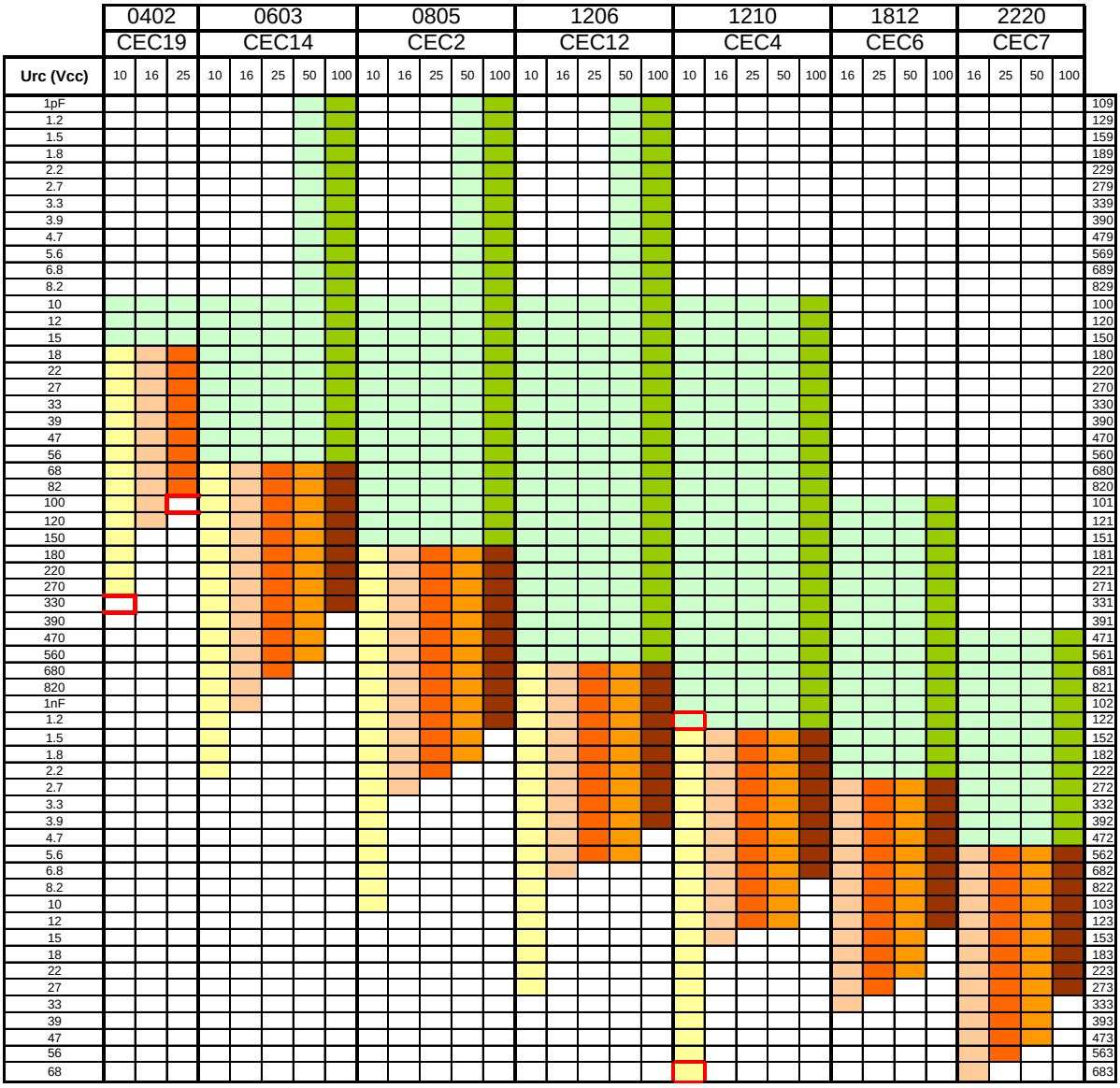
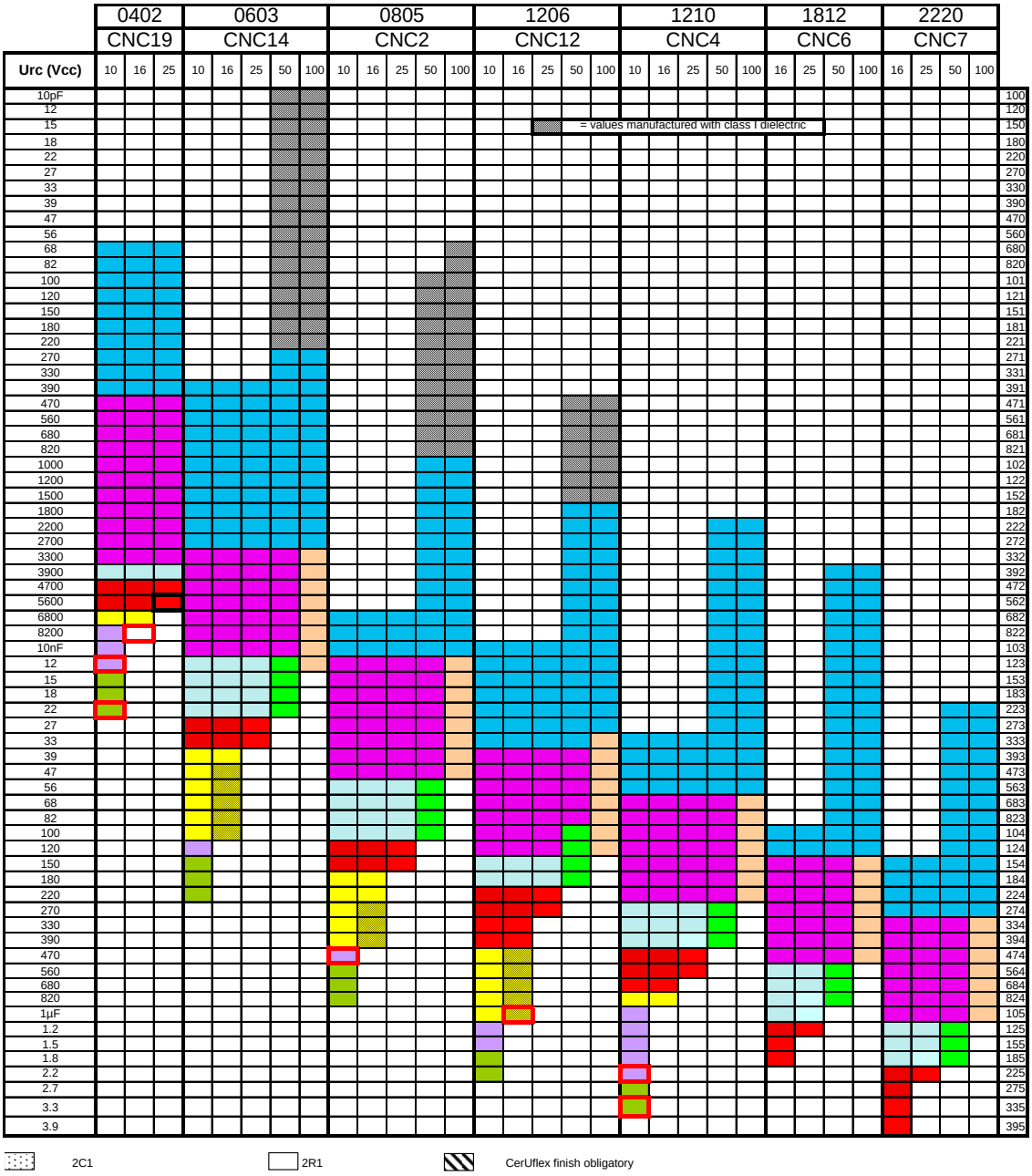
The ranges proposed for evaluation are presented hereunder:

Class I 0402-2220 10-100V ranges:



: Parts chosen for evaluation

Class II 0402-2220 10-100V ranges:

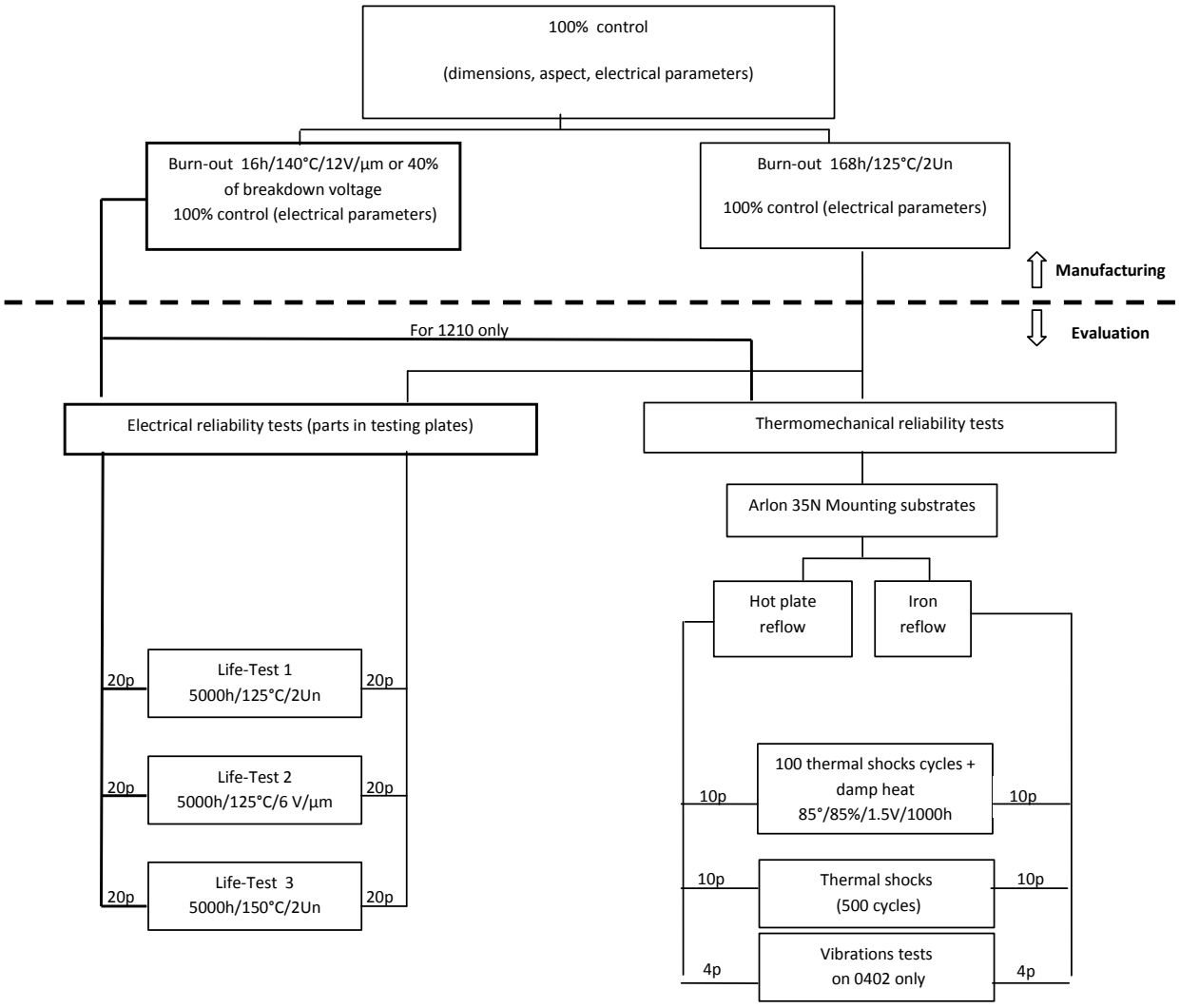


: Parts chosen for evaluation

Besides the development of the ranges, it has also be planned to work on :

- The definition of the best burn-in conditions for the low voltage ranges. The question was to know whether the twice rated voltage conditions was the best one as the voltage/dielectric thickness may become smaller than for 50 or 100V rated parts
- Increasing the data quantity by replacing the classical step-stress by accelerated life-time tests (up to 5000 hours) with several different voltage/temperature (up to 150°C) conditions and a minimum of 20 parts for each test
- The validation (from size 0402 to size 1210) of mounting conditions with the aim to compare 10V rated parts and 16V rated parts
- The verification than iron soldering which is the mounting process used for repairs is adapted to these parts which may be sensitive to thermomechanical stresses because of their high metal/ceramic ratio.

TESTS PROGRAMS



RESULTS

This work is still ongoing. So, only partial conclusions can be outlined by now. These conclusions are :

- The development of size 0402 is still in progress. Their manufacturing is not a problem, but we had to redesign an equipment to control, measure and burn-in correctly these very small dimensions parts. To overcome the weak point of our standard equipment (an intermittent contact) we had to develop a new tooling using very specific test probes. This difficulty is now solved and the evaluation is going on.

- The 10 Volts rated parts are very reliable as life-time tests (up to 4000 hours) have demonstrated it. It has also been confirmed that the flexible termination has a positive role on the reliability.

- For burn-in conditions the results are still under consideration. The increase of the burn-in voltage gradient allows to discriminate better the weak parts, but the right increase has still to be defined accurately.

- Regarding mounting, the parts are suitable for surface mounting, whatever the board material and the mounting process are. Iron soldering can be used for repair but we recommend to preheat correctly the parts before soldering, to avoid the direct contact of the ceramic with the iron tip and to cool gently the ceramic capacitors after repair.

NB : Work done with support of CNES.