Second Set of Components

Due to modifications on the design of the HV filter for the VPTs, a new set of components (Resistors and Capacitors) where tested.

For the purpose of cataloguing them, they were given serial numbers of the type

$X.T.Y - S.ZZ$

- X is either "R" (for Resistors) or "C" for (Capacitors)
- T.Y is the type ID of the Component: e.g. T1 T2 T3… TN for "N" different components
- S.ZZ is the sample ID. In the case of 10 samples then ZZ will range from 01 to 10
- Example: RT4 S06 is the resistor with the type ID 04 and sample id 06

This provided easy identification and unique to each particular component. This identification was written on paper with graphite pencils and placed with the component on individual borosilicate glass vials. These allow for storing, manipulation and irradiation, without the risk of mixing the components.

The identification for these components was assigned as follows. Please note that the RS number shown is the full catalogue reference number for the year 2005.

RS Number	XTY identification	Component Type	Nominal Value	Rating	Quantity
RS – 117 – 316	CT1	Capacitor	1nF	2kV	10
RS – 117 – 300	CT2	Capacitor	470pF	2kV	10
RS – 484 – 4602	RT1	Resistor	22MΩ	2kV	10
RS – 135 – 667	RT2	Resistor	10MΩ	0.125W	10
RS – 131 – 132	RT3	Resistor	100Ω	0.125W	10
RS – 484 - 4595	RT4	Resistor	10MΩ	2kV	10

Irradiation

As the number of components was large in comparison with the previous set, the time required to do the measurements was at least three times grater. Therefore it was decided to split the whole set in two groups so that it could be possible to irradiate some components while other where being tested, and vice versa.

This groups where separated according on how easy they where to tests, compare with the others; so the first group was RT1, RT2, RT4 and the second one was RT3, CT1 and CT2.

There were placed on a metal box for EM Shielding in a random distribution such as the one displayed on Figure 1.

- The first group received a dose of radiation of 134kGy with a variation of 70% - 50% due to geometric factors.
- The second group received a dose of radiation of 136 kGy with a variation of ± 30% due to geometric factors.

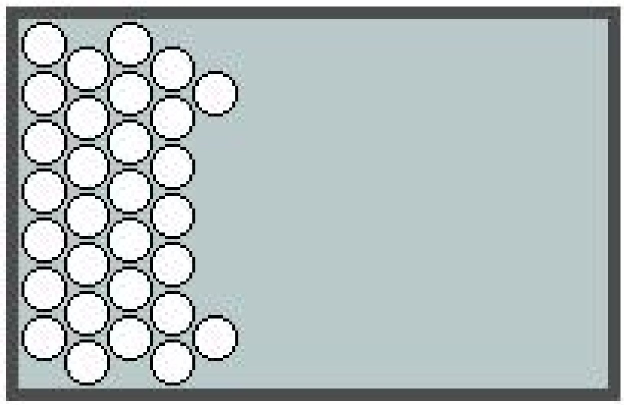


Figure 1 Vials Array

Testing Methodology

The same methods as with the previous set of components where used, with the exception that this time, it was thoroughly tested the resistors before irradiation, as the effect of frequency was not noticed on previous experiments but after the components where irradiated.

For this, it was used the same Impedance Analyser from HP, model 4192A LF. Set to measure the passive component, in parallel with the reactive component. In almost every case, this was a resistor parallel to a capacitor. The exemption was RT3 which I will explain later.

For this setting, the impedance analyzer provides the readings in fractions of Farads and fractions of Siemens. Because of this, this papers reports our findings in these units, so as to show the reader the same values observed on the instruments.

The second change on the methodology derived on the repeatability of the results, after some preliminary test, it was proved that repeating the same test 5 times showed approximately the same statistical value for repeating the test 10 times as done before.

- Therefore, every sample of every component was tested 5 times at each individual frequency.
- The frequency measured where 10Hz, 100Hz, 1kHz, 10kHz, 100kHz, 1MHz, and 10MHz. Providing a test at every decade that the impedance analyser could supply.
- The leakages current was calculated by measuring the voltage across a resistor, using the same jig used before for this purpose on previous chapters of this paper.
- The charts shown below reflect the measurements across the component type. I.e. each maximum is the maximum recorded between all the tests of each sample for that type; the same applies to the minima and of course the averages.

For Measuring the Leakage Current, it was used the same JIG used before and described in Figure 2 with the main difference of the power supply. The High Voltage Power Supply used for this experiment was the SRS (Stanford Research System), Model PS310/1250V - 25W.

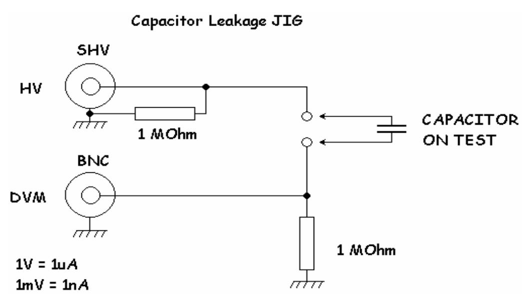


Figure 2 Capacitor Leakage Current JIG

It was observed that when using this power supply, the voltmeter showed a reading of 0V when no capacitor was connected. The voltmeter also showed a reading of 0V before the voltage was applied and a capacitor was connected.

This suggests that part of the measurement of leakage current on the previous experiments had a strong influence from the power supply, and therefore, as it was done, it was imperative to compensate for the misleading readings on the voltmeter.

In this case however, no compensation was required as the readings from the voltmeter were due to HV applied to the JIG alone.

CT1: Capacitor of Type 1 (RS – 117 – 316) 1nF

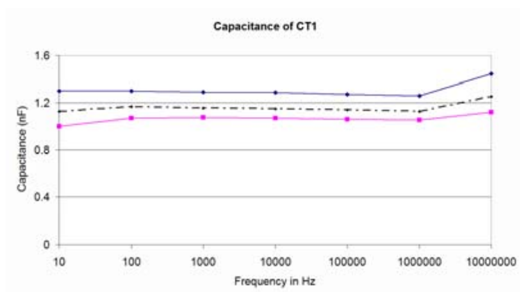
<table>
<tr><th></th><th>Before Radiation</th><th>After Radiation</th></tr>
<tr><td>Capacitance</td><td>

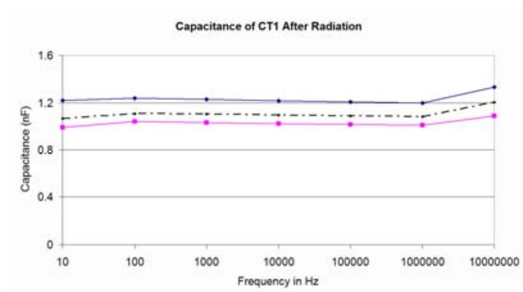
Figure 3</td><td>

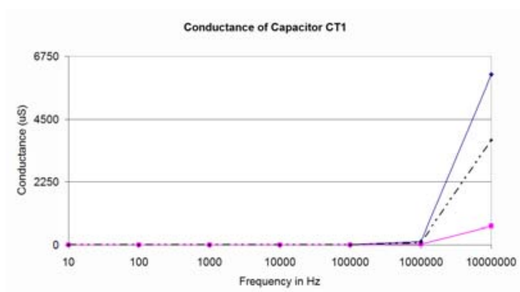
Figure 4</td></tr>
<tr><td>Conductance</td><td>

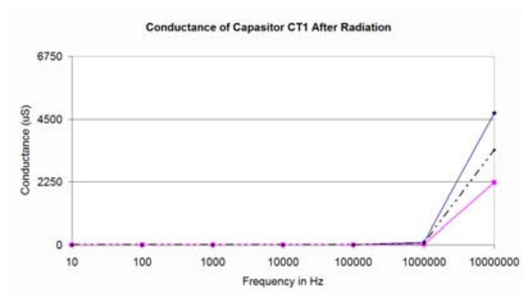
Figure 5</td><td>

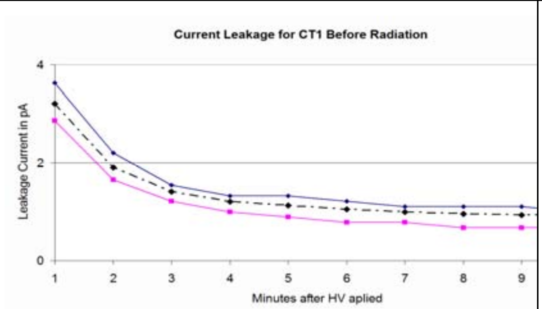
Figure 6</td></tr>
<tr><td>Leakage Current</td><td>

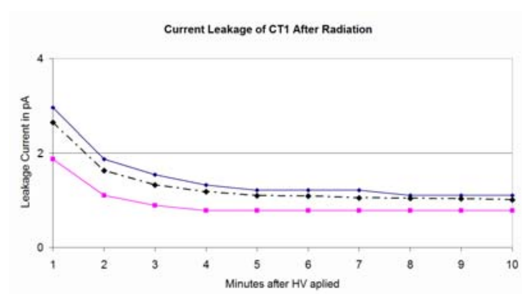
Figure 7</td><td>

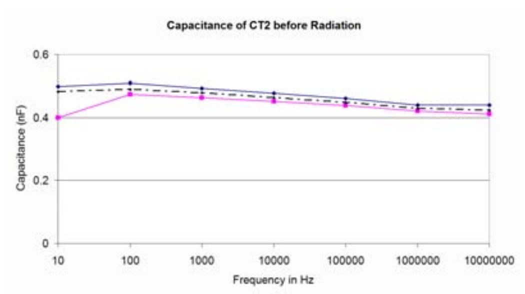
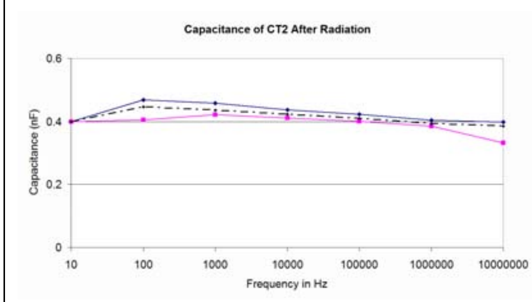
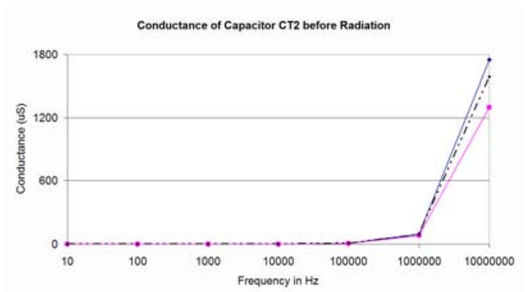
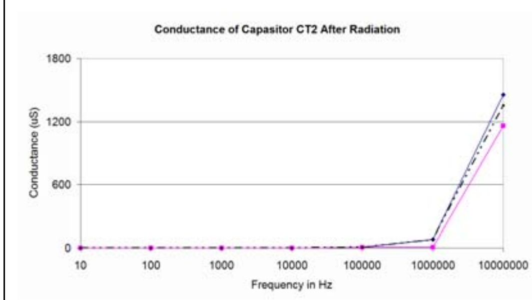
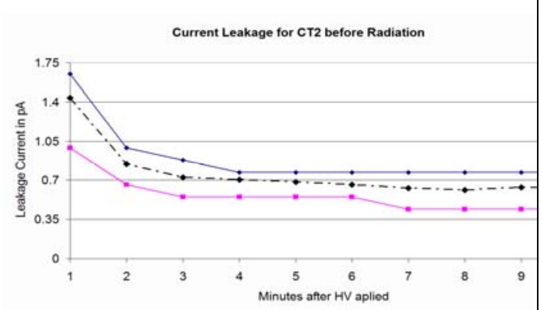
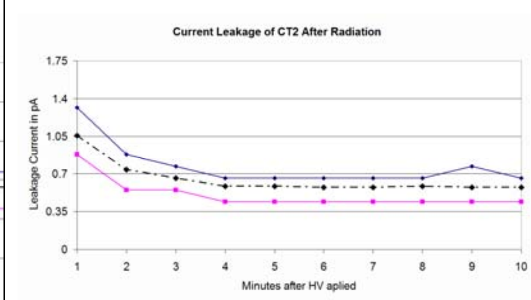
Figure 8</td></tr>
</table>

As it can be seen from Figure 3 the capacitor samples varied very little between them and across frequencies, assuring that overall, this type of capacitor are more reliable than the previous tested. Furthermore Figure 4 shows that the capacitor not only suffered a little damage (les than 10% change) but that they got closer to the nominal value of 1nF.

Figure 7 and Figure 8 show that magnitude leakage current seems also to reduce with radiation as it has been reported on previous papers.

The Leakage Current is shown to improve as well by reducing the time it takes to stable to 1pA

CT2: Capacitor of Type 2 (RS – 117 – 300) 470pF

	Before Radiation	**After Radiation**
Capacitance	 **Figure 9**	 **Figure 10**
Conductance	 **Figure 11**	 **Figure 12**
Leakage Current	 **Figure 13**	 **Figure 14**

CT2 shows to be a bit less stable with frequency as it does not remain as constant as CT1. However, overall the rate of change is almost negligible. The nominal reliability of the capacitor is tighter; this means that, as it can be seen from Figure 9 and Figure 10, the variance is minimal at each frequencies spots.

Figure 9 and Figure 10 also shows that the radiation damage suffered by CT2 is acceptable under the operation conditions.

Figure 11 and Figure 12 shows that the conductivity of the capacitor suffered little to no damage at frequencies less that 1MHz and a slight improvement at high frequencies has been noticed.

The leakage current has also an improvement taking 4 minutes instead of 7 to stable to 0.6pA as it can be seen from Figure 13 and Figure 14

RT1: Resistor of Type 1 (RS – 484 – 4602) 22MΩ

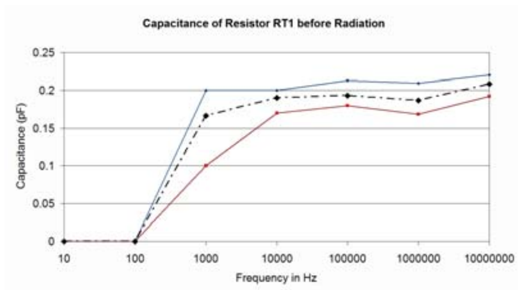
<table>
<tr><th></th><th>Before Radiation</th><th>After Radiation</th></tr>
<tr><td>Capacitance</td><td>

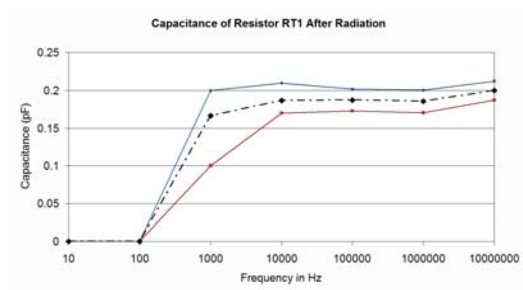
Figure 15</td><td>

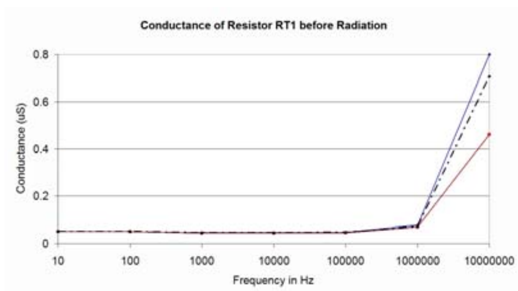
Figure 16</td></tr>
<tr><td>Conductance</td><td>

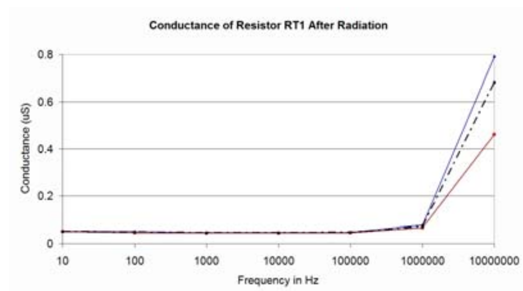
Figure 17</td><td>

Figure 18</td></tr>
</table>

Figure 15 and Figure 16 shows the shunt capacitance across the resistor. Obviously at very small frequencies, this component is almost none existent as the capacitive impedance tends to a open circuit. However, at intermediate and high frequencies this component appears to be constant.

From Figure 17 and Figure 18 it can be seen that the resistor suffered negligible damage due to irradiation to their conductance, and also from Figure 15 and Figure 16 the small change of the shunt capacitance tends to an improvement.

RT2: Resistor of Type 2 (RS – 135 – 667) 10MΩ

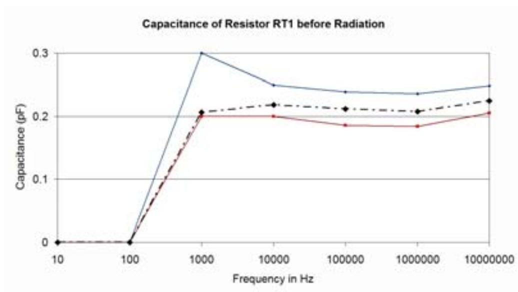
<table>
<tr><th></th><th>Before Radiation</th><th>After Radiation</th></tr>
<tr><td>Capacitance</td><td>


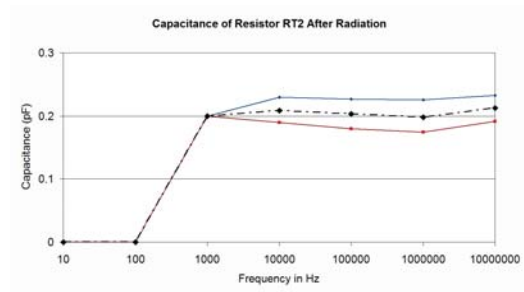
Figure 19</td><td>


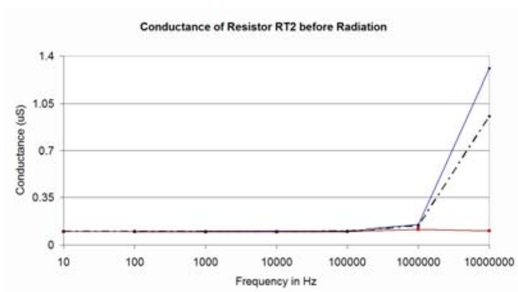
Figure 20</td></tr>
<tr><td>Conductance</td><td>


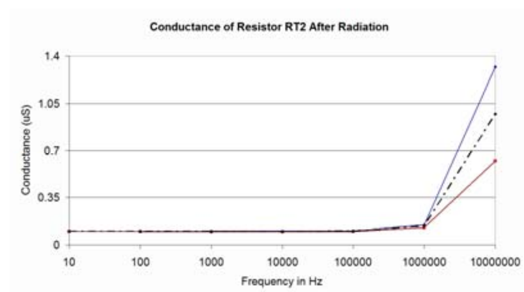
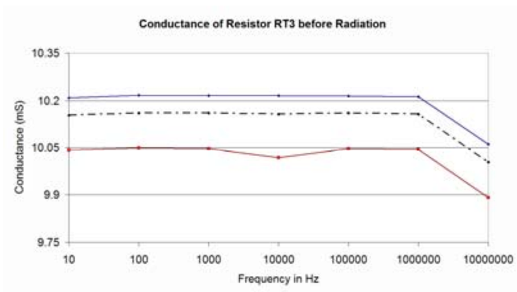
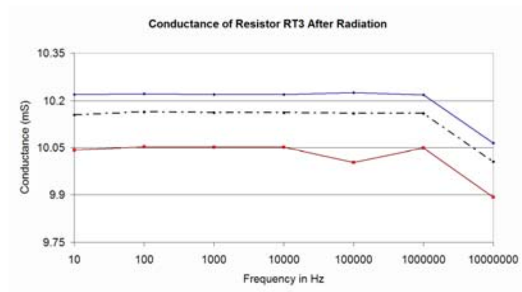
Figure 21</td><td>


Figure 22</td></tr>
</table>

From Figure 19 and Figure 20 it can be seen a slight improvement on the shunt capacitance due to radiation. And if it was not because of an improbable measurement at 1kHz before irradiation, both charts would be almost identical to each other, proving the consistency of the samples of these resistors.

Figure 21 and Figure 22 shows the same behaviour on the conductive side of the story. The mean in chart Figure 21 clearly shows that the minimum at 10MHz must have been an improbable measurement which should be on the line observed in Figure 22.

RT3: *Resistor of Type 3 (RS – 131 – 132) 100Ω*

	Before Radiation	**After Radiation**
Conductance	 **Figure 23**	 **Figure 24**

As mention before RT3 was an exception to the parallel R-C model. The reactive component was so small that for frequencies up to 10 kHz the reactive component was asymptotical to capacitance, however for frequencies above this one, the asymptote lies on inductance in a serial L-R model.

The measurements in Ohms from the serial model where inverted to Siemens for two reasons:

- Data at same units and scales are easier to compare and analyze
- Siemens has been used throughout this report.

One of the focal point of the graphs shown is what happens at high frequencies. All the previous cases shown that conductance should increase with frequency, which is true for parallel RC configuration, where as frequencies increase the impedance due to C decreases to a short circuit making the model “more conductive”. Since at high frequencies RT3 is more inductive, the impedance increases to a open circuit and hence the model is “less conductive”

What it is surprising as well is the little damage the resistors have endured.

RT4: Resistor of Type 4 (RS – 484 - 4595) 10MΩ

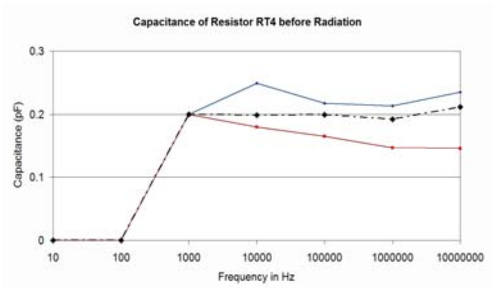
<table>
<tr><th></th><th>Before Radiation</th><th>After Radiation</th></tr>
<tr><td>Capacitance</td><td>

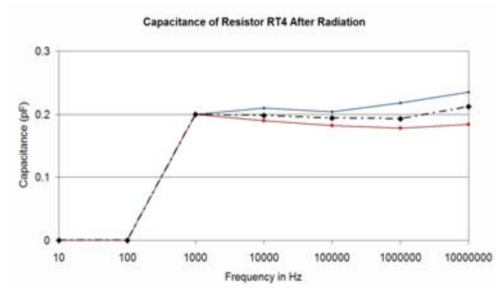
Figure 25</td><td>

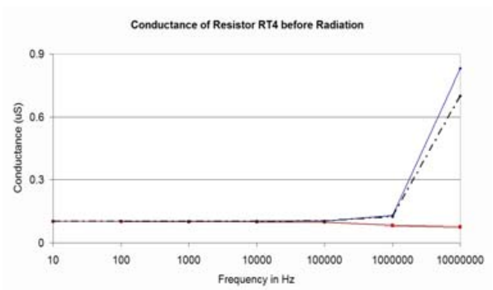
Figure 26</td></tr>
<tr><td>Conductance</td><td>

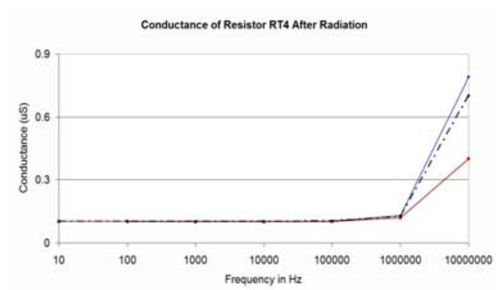
Figure 27</td><td>

Figure 28</td></tr>
</table>

RT4 shows also it hardness to radiation as it can be seen from Figure 25 and Figure 26 where the shunt capacitance is almost unaffected.

The same can be said about the conductance shown in Figure 27 and Figure 28.

Conclusion

Due to changes on the High Voltage filter for the VPTs of the CMS Endcap a new set of components needed testing for radiation hardness.

This paper reported the findings from the measurement experiments of these components and concludes that due to the negligible effects radiation has on these samples; it recommends their use for the HV filters.