Gamma radiation in ceramic capacitors: a study for space missions

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Abstract. We studied the real time effects of the gamma radiation in ceramic capacitors, in order to evaluate the effects of cosmic radiation on these devices. Space missions have electronic circuits with various types of devices, many studies have been done on semiconductor devices exposed to gamma radiation, but almost no studies for passive components, in particular ceramic capacitors. Commercially sold ceramic capacitors were exposed to gamma radiation, and the capacitance was measured before and after exposure. The results clearly show that the capacitance decreases with exposure to gamma radiation. We confirmed this observation in a real time capacitance measurement, obtained using a data logging system developed by us using the open source Arduino platform.

1. Introduction

An embedded system is an electronic circuit coupled to a complex mechanical system. This electronic circuit can be analog or digital, and it has the function of making the control of these systems, or health monitoring of complex electromechanical systems.

The cosmic radiation causes changes the electronic circuits behavior, such as space missions are heavily exposed to these radiations they need proper shield to their electronic systems. Long operating range missions require great precision in inertial navigation electronic systems. The shield do not fully prevent the radioactive penetration, as well passive components end up accumulating doses during the long stay in space, and therefore undergo changes in its operation.

Capacitors are part of embedded systems, and their behavior is directly related to its dielectric, which is the insulating material. The dielectric has the function of facilitating the flow of the electric field and the dielectric constant is the parameter that measures this ability. A ceramic capacitor has a high dielectric constant, and insulating material is used as a mixture of quartz, feldspar and alumina. Each of these minerals have a significant contribution to the electrical properties of the capacitor.

When the ceramic insulator is irradiated by some kind of ionizing radiation, electrons are raised to the conduction band, leaving holes at the valence band. The pre-existence of defects inside of insulator can trap these free charges, changing the amount of free carriers and electric dipoles in the material. Ionizing radiation causes an increase in the number of free carriers, and a reduction in the number of electric dipoles, which in turn reduces the electrical permeability of the alumina and hence reduces the capacitance of the material [1]. Subsequent stimulation by heat or light leads to absorption of energy by the trapped electrons, causing a transition
to the conduction band and posterior recombination with localized trapped holes resulting in luminescence emission [2].

The ASTER mission is the first attempt of Brazil to send an object to deep space [3]. The mission will have navigation and attitude control systems [4] and measuring instruments such as a topographic profile system [5].

This study sought to determine the changes in capacitance of ceramic capacitors due to exposure to doses between 1 and 20 Gy. These capacitors have alumina as dielectric material, and observed in earlier studies the capacitance of alumina decreases with increasing dose, due to the ionization processes and the disruptions of electric dipoles within the material [1].

Therefore, in this study we observed the effects of gamma radiation in ceramic capacitors, measuring the capacitance before and after exposure. We study the permanence of the effects in long time, if there is extinction effect after heating, as it occurs in the alumina thermoluminescence processes [6]. In addition, we made a real time measurement of capacitance during exposure to gamma source, using a data logging system dedicated to this purpose and developed by our group using the open source Arduino platform.

2. Experimental

We use ceramic capacitors obtained in the retail of electronic components, the nominal values are 10 nF and 100 nF, 50 V isolation voltage and tolerance of 20% in the nominal value. Each capacitor was identified and their capacitance was measured using precision capacimeter MINIPA MXB-821.

We recorded the actual values of each capacitor and then sent to irradiate in samples with three capacitors. Each sample was irradiated with a specific dose, and the values range was 1 to 20 Gy. We used a $^{60}$Co gamma-source in RT, with 28.76 Gy/h. After exposure, we measured capacitance values and calculate the change in capacitance:

$$\Delta C = C_a - C_b$$

where $C_a$ is the average capacitance before exposure and $C_b$ is the average capacitance after.

To determine if the effect of radiation is permanent and there is a relation with the thermoluminescence phenomena, we repeated the procedure with intervals of 7 and 37 days. In addition, we repeat the procedure and then heat it to 300 °C for 30 s and then measure the capacitance values.

Finally, we build an autonomous system of capacitance measurement, in order to record the effect of radiation on the capacitor in real time. The capacitance measurement consisted of measuring the capacitor charge time tau in a series resistor capacitor circuit:

$$C = \frac{1}{R \cdot \tau}$$

where $C$ is the instantaneous capacitance, $R$ is the series resistor (1 MΩ), and $\tau$ is the time at which the capacitor voltage reaches 63.2% of the applied voltage in the circuit [7].

An Arduino microcontroller was used to perform the measurement time constant. The RC circuit is connected to a microcontroller port, and the capacitor is connected to the input of the analog to digital converter (AD). A third pin is used to completely discharge the capacitor. The Arduino input-output pins (IOpins) can be in one of these three electrical states, a high output state (5 V), low output state (0 V) and a high impedance state (tristate). A high output state and low output state have a low impedance, because the IOpins is in output mode. When the IOpin is in input state, it has a high input impedance. The complete experimental apparatus to capacitance measurement is shown in figure 1. The capacitance measurement algorithm is shown in table 1.
Table 1. Capacitance measurement algorithm

| Step | Action |
|------|--------|
| 1    | Set discharge pin to input mode. |
| 2    | Set charge pin to output mode. |
| 3    | Get the start time $t_s = t$ in the time register. |
| 4    | Set charge pin to high output. |
| 5    | Check the voltage in A/D register. |
| 6    | Wait until the voltage on the A/D register is equal to 63.2% of output voltage. |
| 7    | Calculate the charge time: $\tau = t_i - t$. |
| 8    | Write $\tau$ value in a small disk card (SD card). |
| 9    | Set discharge pin to output mode. |
| 10   | Set discharge pin to low output. |
| 11   | Go to step 1 until it ends. |

Additionally it was placed a charge counter circuit to measure the emission source during the experiment. The sensor is a PIN photo-diode, model TEND5000, covered with aluminum foil to filter the alpha and beta particles. An amplifier circuit charge counter in conjunction with a voltage comparator is used to generate pulses for each received gamma photon. These pulses are connected directly to the clock pin of the Arduino counters. The main program will stop counting at scheduled time cycles for each 30 s, calculates how many pulses were counted during 1 s, and stores the value of counts per second on a memory card.

Figure 1. Capacitance measurement setup: (a) input test voltage, (b) capacitor under test circuit and (c) Capacitor charge behavior.

3. Results
Figure 2 shows the results of changing capacitance as a function of absorbed dose in 10 nF capacitors. It is observed that the higher the dose, the greater the difference in capacitance, agreeing with the results previously presented in our studies [1]. To confirm the results, repeat the test with 100 nF capacitor using an Agilent 4294A impedance analyzer, figure 3 shows...
the results. The curves of Figures 2 and 3 have a similar behavior but the magnitude $\Delta C$ is greater in figure 3. This difference is due to difference of calibration equipment and the type of meter, in figure 2 is a capacimeter, while equipment in figure 3 is an impedance analyzer. The impedance analyzer is an instrument that measures the complex impedance of the device, and from this information it calculates the capacitance. The capacimeter measuring capacitance directly, through the charge and discharge method.

![Graph 1: 10nF Capacitors](image1)

**Figure 2.** Changing in capacitance due gamma radiation for 10 nF capacitors.

![Graph 2: 100nF Capacitors](image2)

**Figure 3.** Changing in capacitance due gamma radiation for 100nF capacitors.

Figure 4 shows the result of the capacitance change to a 100 nF capacitor during exposure to gamma rays. In the same figure, we show the emission intensity of the source in counts per second (CPS). After the experiment the component absorbed approximately 19.6 Gy. As expected, we found that the device capacitance decreases during exposure. The total capacitance decrease was approximately 3 nF.

![Graph 3: 100nF Capacitors with CPS](image3)

**Figure 4.** Changing in capacitance due gamma radiation for 100nF capacitors.

To determine the effect of radiation on the capacitor is permanent and if it is correlated with
the thermo-luminescence (TL) phenomena, repeat the test and follow the deltaC variation due to the dose over time and with heat treatment. The results are displayed in table 2. We note that the effect tends to disappear with the passing of time, indicating that the phenomenon is unstable, probably the ink covering the capacitors is not enough to contain all the ambient light, and should cause a decay as is seen in photoemission ceramic materials in optically stimulated luminescence measurements (OSL). The heating of the capacitors eliminates all the changes caused by radiation. Thus, we believe that the observed effect is related to processes involved in thermoluminescence (TL).

Table 2. Capacitance permanence test

| Dose (Gy) | 7 days | 37 days | 300 °C for 30 s |
|-----------|--------|---------|----------------|
| 1         | 0.23   | 0.05    | 0              |
| 3         | 0.25   | 0.09    | 0              |
| 6         | 0.28   | 0.11    | 0              |
| 9         | 0.30   | 0.22    | 0              |
| 20        | 0.34   | 0.2     | 0              |

4. Conclusions
From an engineering point of view, the change in the observed capacitance is significant, therefore, a good shielding of electronic circuitry is required for deep space missions, or from the results obtained, we can create compensation circuits for the dose absorbed by the systems electronics, eliminating the shield and gaining space for more payload on the mission.

Gamma radiation incident on the ceramic capacitors was not enough to make permanent changes occur in the dielectric, justifying the return of the original value of capacitance within a week. For be temporary, the capacitor can be used to detect gamma radiation. Or, it could be calculated by measuring the absorbed dose reduction of capacitance in the first 24 hours in the event of a nuclear accident.

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