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EFFECTS OF GAMMA RADIATION ON COMMERCIAL OPERATIONAL AMPLIFIERS

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ABSTRACT

The operational amplifiers are widely used in nuclear instrumentation. Their applications span the signal conditioning circuits, analog instrumentation, amplifiers, converters, oscillators and others. If an operational amplifier is used to work in a radiation environment, the device suffers degradation in its performance leading to the bad work in the systems. Some of these devices are designed as rad-hard components and therefore the effects of radiation damage are minimized, however its main disadvantage is the high cost and difficult to find in the market. As an alternative one can use the conventional electronic components available in the market and named COTS (Commercially Available Off-The-Shelf) but they must be tested under a radiation environment. In this work the effect of the radiation damage is studied in two typical operational amplifiers. Some electric parameters of these devices were measured for different gamma radiation doses and they were working at different input signal frequencies. A ^{60}Co isotopic radiation source was used and the results show that there is a certain degradation of the device depending on the radiation absorbed dose.

1. INTRODUCTION

An electronic device which it works in a radiation environment can present degradation due to the damage [1] occurred in the semiconductor lattice. The strategy applied to overcome this problem is to design electronic devices with special internal structures with radiation hardness (rad-hard). These components usually are available in the international market but, their sales can suffer restrictions. The other strategy is to employ common electronic components previously tested in a radiation environment to define its range of application. This strategy presents a viable alternative, since it is possible to test and define previously the range of validity of the components. In this work, some electric parameters measurements are showed using COTS electronics components. Two types of operational amplifiers [2] (amp-op), types LM741 and CA3140, were used. The radiation damages on the parameters "closed loop gain" and "slew rate" for both amplifiers using as input a square shaped electric signal with three different frequencies were studied.

2. MECHANISMS OF RADIATION DAMAGES

The two basic mechanisms that affect the semiconductor devices are "displacement damage" and "ionizing damage" [3]. In the displacement damage the incident radiation displaces silicon atoms from crystal lattice and therefore it alters the electronic characteristics of the material. In the ionization damage, the energy of the ionization process is absorbed in insulating layers and release charge carriers which they diffuse to other location. Once these charge carriers are moved, they are trapped and produce an unintended concentration of charge. Both mechanisms are important in electronic devices [3]. The ionization damage depends mainly on the absorbed energy, independent of the type of radiation. The tests in electronic devices to send to the space can be made in laboratory using isotopic sources, as ^{60}Co for example. This fact permit simulates the space environment although in the space the radiation is mainly in the particle form (electrons, protons, neutrons).

In the digital circuits, the ionization damage creates electron-hole pairs [3]. The electrons are quite mobile and move to positive electrode. The holes move by a complex mechanisms and have greater probability to be trapped in the oxide volume, generally in interfaces. In the semiconductors, these traps will be able to induce undesired electric current modifying the device design conditions. A schematic diagram of the mechanism of performance of the effect of the radiation in an electronic component is shown in the Fig. 1.

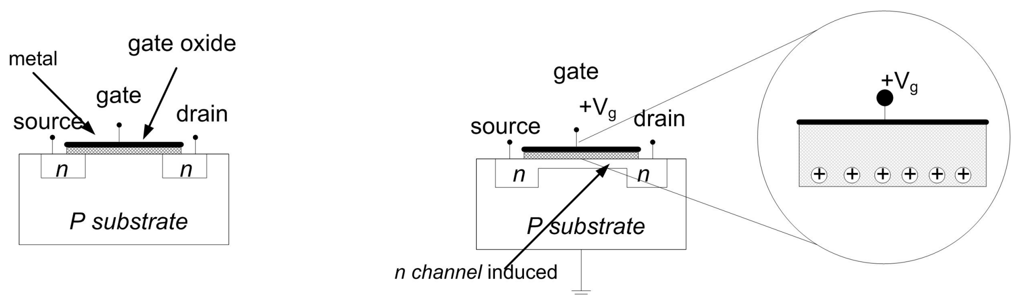

Figure 1 – The schematic cross section of an n-channel MOSFET and the trapped hole at the silicon-oxide interface.

In the Fig. 1 two *n* type regions was diffused t in a *p* substrate. One is defined as source and another as drain. If we apply a potential difference between the source and the drain will not possible appear an electric current because the substratum is biased in a negative potential reversely polarizing the *pn* junctions. The metallic electrode works as an isolated gate. If a positive potential is applied to the gate, the field generated for it will attract electrons for this region. As result, the substrate region will change its characteristic of *p* type to *n* type and will be induced an *n* type canal, as shown in Fig. 1. This continuous region of *n* type allows a current flow in the transistor and it can be controlled by the potential applied in the gate. In Fig. 1 a detail of the gate and silicon oxide is showed. The holes formed by ionizing radiation can accumulate in the interface and produce an increase of positive charges. This can induce currents and errors in the device or its burnout. In the design of operational amplifiers [4] several transistors and semiconductors based on this technology are present; therefore they suffer damages from this nature.

3. OPERATIONAL AMPLIFIERS

Operational amplifiers are commonly used in circuits of nuclear instrumentation. In order to understand how the operational amplifier works one can say that an input signal, V_i, is amplified by a factor "*A*" and the output signal is given by $V_o = A \cdot V_i$. In general, there are three basic circuit configurations: Inverting amplifier, Non-inverting amplifier, and Buffer [4]. In this work only inverting circuit configuration is used to evaluate how gamma radiation can alter some characteristic of the device.

The operational amplifiers are used in several electronic circuits and with great uses in the nuclear applications. The term operational amplifier (op amp) was fist used in 1940 to identify devices that could perform various mathematical operations. Initially they were made from vacuum tubes consuming great amount of energy and space, today, it is constituted by integrated circuits highly efficient and in general of low cost.

The Fig. 2 illustrates its standard symbol. It amplifies the voltage difference; $V_d = V_p - V_n$ applied on the input port and produces a voltage V_o on the output port. The ideal model assumes infinite gain *(a)*, infinite input resistance and zero output resistance. In this way, we have that:

$$V_o = aV_d = a(V_p - V_n) \quad . \tag{1}$$

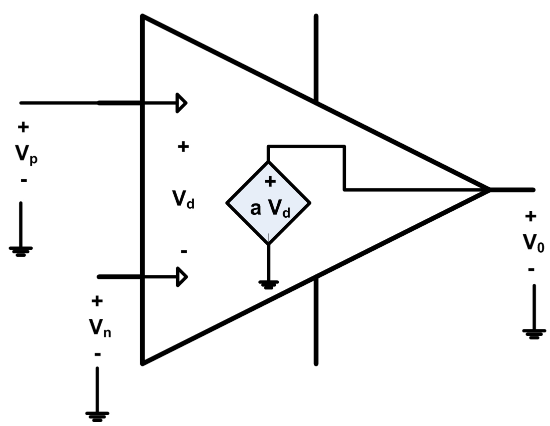

Figure 2 – Symbol for operational amplifiers.

A basic application of this device is as inverting amplifier, as shown in Fig. 3. The input terminal of + V_p is called *non inverting input* whereas the input – V_n is the *inverting input*. In the inverting applications, the input signal is applied to V_n and the V_p input is grounded. The values R_1 and R_2 will define the real gain *A*, as showed by equation (6) .Using the diagram circuit of Fig. 3 the relationship between the input voltage and the output voltage can be derived.

Let us consider initially V_o equal zero and V_p grounded, thus,

$$V_n = V_i \frac{R_2}{R_1 + R_2} \tag{2}$$

Considering now $V_i = 0$,

$$V_n = V_o \frac{R_1}{R_1 + R_2} \tag{3}$$

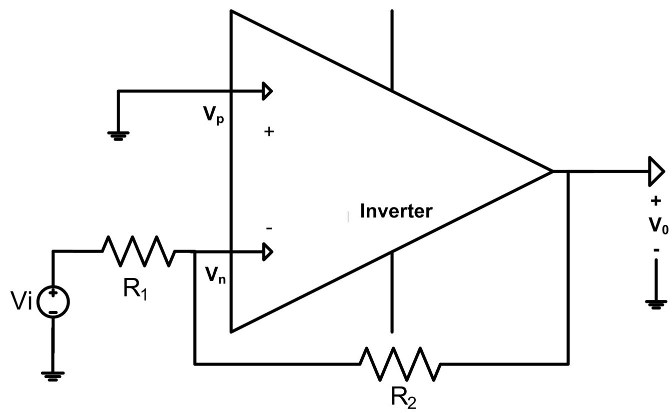

Figure 3 – Diagram of the inverting operational amplifier.

Combining the equations (2) and (3), we have:

$$V_n = V_o \frac{R_1}{R_1 + R_2} + V_i \frac{R_2}{R_1 + R_2} \tag{4}$$

Using the equation (1) and rearranging,

$$A = \frac{V_o}{V_i} = 1 - \left(\frac{1}{b}\right)\left(\frac{1}{1 + {}^{1}\!/_{ab}}\right) \tag{5}$$

Where $b = \frac{R_1}{R_1 + R_2}$. As the value of $b \leq 1$, the closed loop gain is negative and bigger than unit. Substituting, $a = \infty$ the gain will be:

$$A = 1 - \frac{1}{b} = -\frac{R_2}{R_1} \tag{6}$$

This is an inverting amplifier. With convenient values, R_1 and R_2, the gain will attain 10 to 2000 times.

4. EXPERIMENTAL PROCEDURE

Two types of operational amplifiers (LM741 and CA3140) were used to test radiation damage from an isotopic gamma source of ^{60}Co at LRI – Laboratório de Radiações Ionizantes do IEAv - Instituto de Estudos Avançados. A printed circuit board was built to mount three pairs of inverting operational amplifier. Each one was similar to the diagram showed in Figure 3 and the power supply was chosen to be 12 V. The input signal was a square wave at tree different frequencies: 100 Hz, 1 kHz and 30 kHz. The input and output signals were monitored by using an acquisition card PCI NI6025E, National Instruments. The electrical parameters measured were the closed loop gain and the slew rate. The acquisitions data were controlled using the virtual instrument software built in the LabVIEW platform [5]. In the Figure 4 is showed the printed circuit with the devices exposed to gamma ray source. The irradiation procedures consisted to expose the circuits to 0.8 Gy dose step at 23°C of temperature.

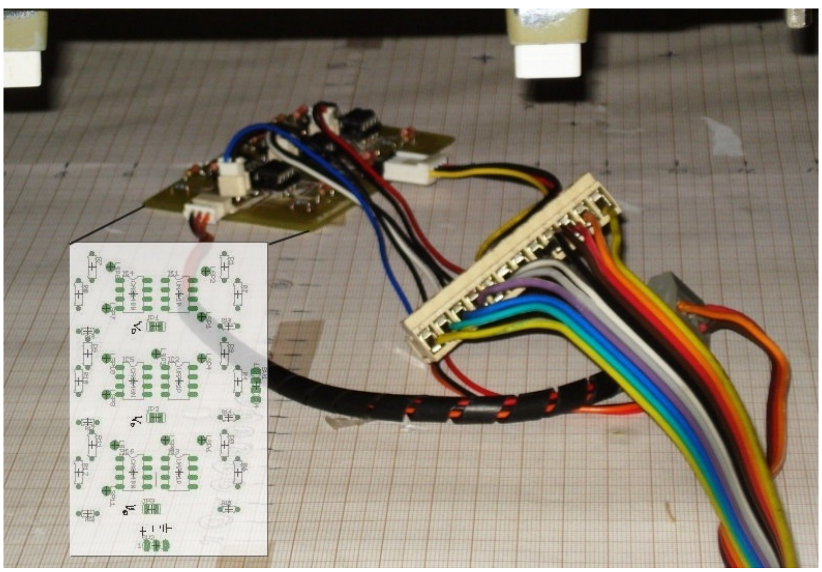

Figure 4 – The printed circuit board, with devices, under gamma irradiation.

5. RESULTS AND DISCUSSIONS

The exposure to gamma radiation affects all the characteristics of the operational amplifiers but its burnt-out depends on its construction robustness. The Fig. 5 and Fig. 6 shows the degradation on the *closed loop gain* for the two types of operational amplifiers as a function of the frequencies and several applied doses.

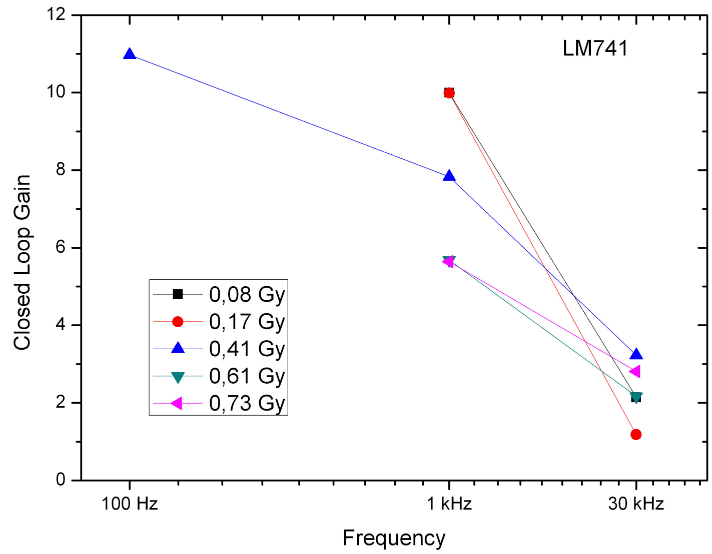

Figure 5 – Closed loop gain of operational amplifier LM741 as function of the frequency, for different dose levels.

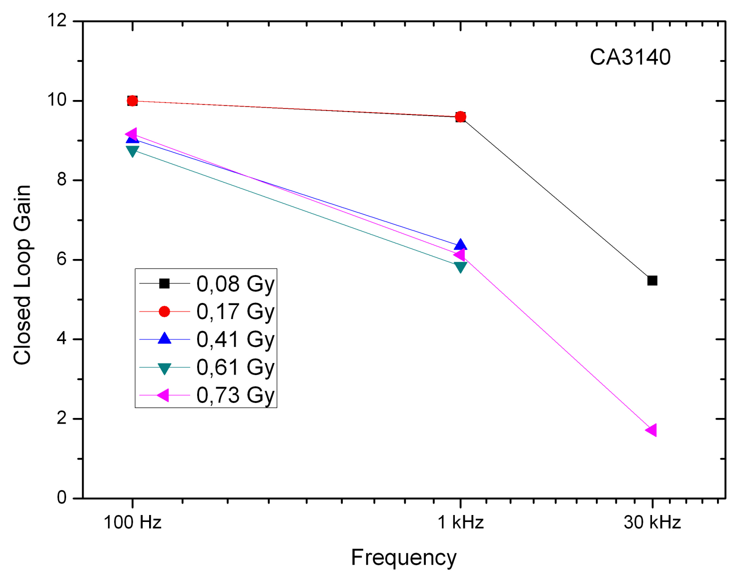

Figure 6 – Closed loop gain of operational amplifier CA3140 as function of the frequency, for different dose levels.

In general, one can observe that the gains of the operational amplifiers are degraded as a function of the absorbed dose and frequency. In this experiment, some values of *closed loop gain* are not shown because some devices were burned during the exposition. At low and high frequencies, 100 Hz and 30 kHz, the amplifiers showed anomalous operation indicating that there is a limit. At 1 kHz frequency the expected behavior was observed.

In Fig. 7 the *slew-rate* are presented in function of dose and some frequencies of input signal.

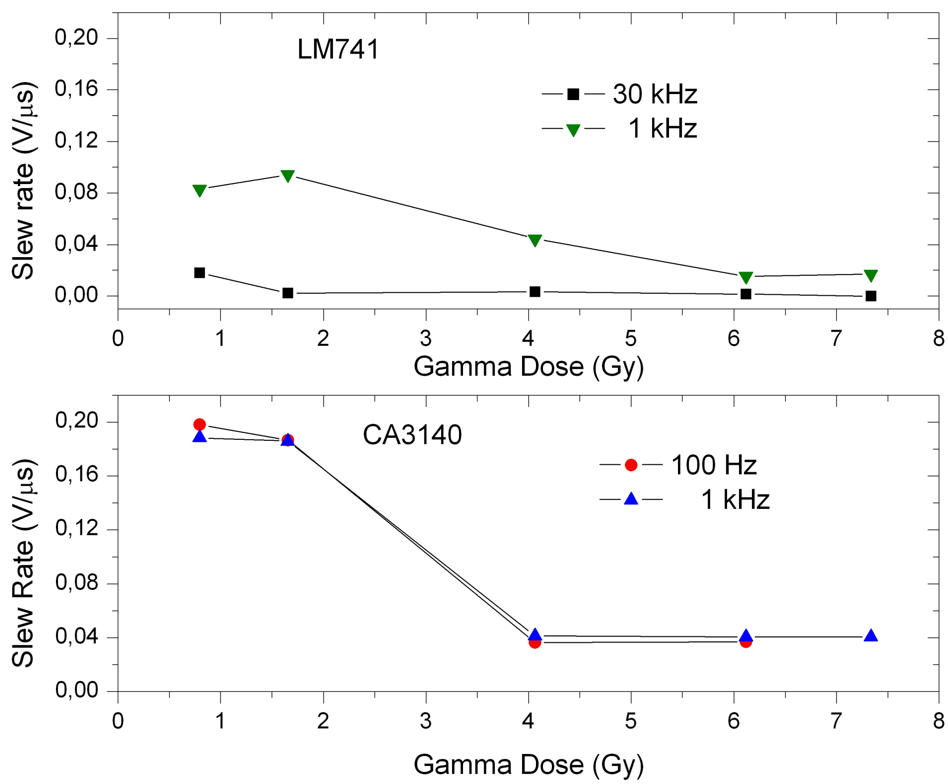

Figure 7 – Slew rate of operational amplifiers CA3140 and LM741 as a function of the frequency, for different absorbed dose.

The *slew rate* decreases for low dose at all frequencies. For low gamma dose levels, a pronounced decrease in this parameter is showed and the rate decrease differs from sample to another. This rate is larger to CA3140 than to LM741.

6. CONCLUSIONS

In this work an initial study of operational amplifiers under gamma radiation was carried. The commercial amplifiers LM741 and CA3140 were used. Experimentally was observed that the gain is drastically decreased as the gamma dose increase. The slew rate has a similar behavior, so, its permit to conclude that the all electrical parameters were shifted beyond the ideal values due radiation damage. The two types of operational amplifiers show differences in their sensitivity to radiation exposure.

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