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High Energy Ions Effects of Plasma Focus Device on Spacecraft Electronics: Experimental Investigation

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Abstract

The ions (in range of 0.1 to 1.0 MeV) radiation effects of operational amplifiers is investigated using MTPF-2 plasma focus device. In this work, High-efficiency commercial LM324 amplifiers that are used in satellites, is placed in front of the focus plasma anode. According to ion irradiation, the offset current and offset voltage and voltage gain of op-amp are investigated.The experimental results show that the ion radation causes the threshold voltage change in n-p junction of the transistors in the op-amp.

Keywords: high density, plasma focus, ion beam, electronic devices

Introduction

The electronic equipment are one of the main components used in satellites[1]. The radiation environment in space has adverse effects in their normal operation of electronic systems[1,2]. High energy ionized particles such as protons, heavy ions and electrons can have observable effects on the semiconductor network[3]. So, in order to prevent the reduction of life or failure of satellites, electronic boards are tested with different radiation sources[4].

Much research has been reported on the effects of gamma rays, X-rays, high-energy particles from radiation sources such as cobalt 60, pulsed lasers, etc. on electronic functions or materials of electronic chips[5,6]. The protons in the radiation belt are the main source (90% of cosmic charged rays) of the dosing environment that electronic equipment experiences in space. Based on advances in electronic components, their sensitivity to low-energy protons could also lead to damage. Based on this, many researches have been done in the field of the effect of low energy protons with a range of 0.1 to 8 MeV on the structure of FET transistors, SRAM terminals, etc[7-9].

One of the dense plasma sources is the focus plasma system, which is one of the most efficient laboratory plasma radiation sources. Plasma Focus device with energy ranges from a few kJ to MJ are able to generate energetic ions with energy more than few hundreds of KeV to tens of MeV. The LM324 operational amplifier is used as a highly functional, low-power chip in satellite electronic systems.

In this paper, a study on the performance of the operational amplifier LM324 is performed under ion radiation . In the following, changes in the operation of this voltage amplifier was investigated.

Experimental setup

- ***Focus plasma device***

A mather focal plasma device with energy of 2.5 kJ is used as a source of ion beams to investigate the damage of the ions on the differential amplifier operation. The main specifications of the MTPF-2 focal plasma device are shown in Table 1.

Table 1. The main specifications of the MTPF-2 focal plasma device

Parameter	value
Anode length	95mm
Anode diameter	29mm
Cathode length	145mm
Capacitor	$13.5\mu F$
Inductance	115nH
Power supply	20KV/100mA
Gas	Hydrogen

Photo of the MTPF-2 device and its internal structure is shown in figure 1.

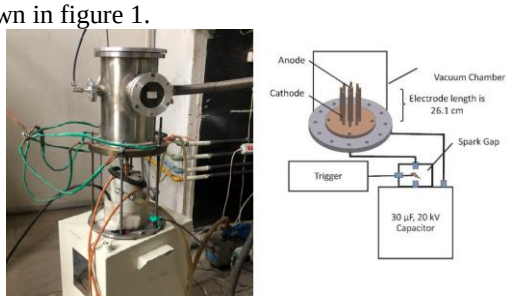

Figure 1. Photo of the MTPF-2 device and its internal structure

- ***LM324***

The LM324 IC is used as a high-voltage operational amplifier with low power consumption in analog instrumentation, amplifiers, converters, oscillators, etc. Important parameters of operational amplifiers are:

- Input offset voltage and current
- Large-signal voltage gain
- Input and output impedance
- Frequency response and bandwidth (BW)
- etc.

In this paper, the characteristics such as changes in output signal, voltage gain, input offset voltage and offset current were investigated. In this work, the LM324 IC uses input dual power supply of ±15 volts and test input was a sinusoidal signal with an amplitude of 10 mV and a frequency of 1KHz with the Function Generator.

Results and discussion

The circuit designed to amplify the voltage is equal to 10. The input(a) and output(b) signal of the circuit by the oscilloscope is shown in figure 2.

The LM324 operational amplifier is used to test radiation damage from the MTPF-2 focal plasma source in the Plasma Laboratory of the Atomic Energy Organization.

In laboratory setup, there is a Faraday cup to measure the energy spectrum of ions and a holder to place the LM324 chip 4 cm from the anode in the focal plasma device. The energy range of ions produced in the plasma focus device is range of 0.1 to 1.0 MeV.

In figure 3, the output signal of the LM324 circuit after exposure to the beam for 20 shot is shown. According to the tests performed for the case of 20 shots, the positive part of the signal is cut. In figure 4, input offset voltage of LM324 op amp is shown. And in figure 5, input offset voltage of LM324 op amp after exposure to ion radiation is shown (probe *1000). In this case, the input offset voltage and input offset current increased from 4.5 mV, 0.120μA to 11 mV, 0.29μA after exposure to ion radiation. A theory for permanent damage in integrated circuits is based on the existing theory of reduced current gain in transistors [3]. Operational amplifiers contain non-standard circuit elements such as p-n-p transistors, gain transistors, resistors, and etc [5]. Radiation causes severe disturbance in the input transistors, which leads to an increase in the mismatch of their input properties. As a result, both the input voltage and input current of the "LM324 differential amplifier" increase dramatically. It is generally expected that the threshold voltage change due to radiation between the transistors in the op-amp will change, leading to an imbalance and thus an increase in the offset voltage [4-6].

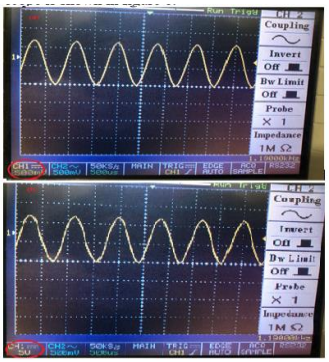

Figure 2. The input(a) and output(b) signal of the circuit by the oscilloscope

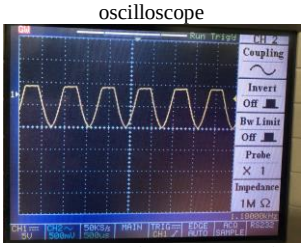

Figure 3. The output signal of the circuit after exposure to ion radiation

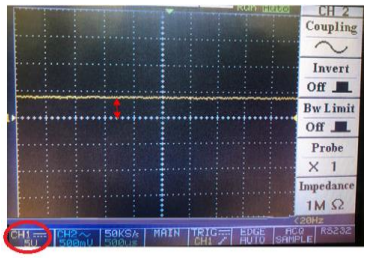

Figure 4. input offset voltage of LM324 op amp

Figure 5. input offset voltage of LM324 op amp after exposure to ion radiation

Conclusions

In this paper, a preliminary study of LM324 operational amplifiers irradiated with ions of PF device was performed. According to the tests performed in the case of 20 shots, the voltage gain of the op amp is reduced and both the input voltage and input current of the "LM324 differential amplifier" increase dramatically. It is generally expected that the threshold voltage change due to radiation between the transistors in the op-amp will change, leading to an imbalance and thus an increase in the offset voltage.

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