

## TRANSIENT IONIZING RADIATION EFFECT OF BIPOLAR OPERATIONAL AMPLIFIERS TO PULSED X-RAYS

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### Abstract

The pulsed ionizing radiation effect of monolithic operational amplifiers is investigated using a flash X-ray facility. The experimental results show that the pulsed ionizing radiation causes voltage surges in the devices and the output voltage recovers linearly after transient disturbance exhibited by a negative peak and a positive peak. The recovery time depends on the amplitude of the positive peak and the inherent slew rate of the devices. The degradation of transient disturbance amplitude and the recovery time versus ionizing dose rate of pulsed X-rays is researched. The relationship of circuit effects to physical mechanisms is investigated in detail. The photocurrent induced by transient ionizing radiation in the PN junctions in the integrated circuits is responsible for the electrical degradation.

### INTRODUCTION

Transient ionizing radiation effects of bipolar analog devices have been studied by many individuals and organizations because they constitute the majority of modern bipolar applications [1]-[7]. In this paper, the transient response of a  $\mu$ A741 operational amplifier in a pulsed X-ray radiation environment is investigated using an intense X-ray flash facility. The objective of the radiation test is to detect and measure the degradation of the critical parameters of the device as a function of radiation dose rate. The radiation tests in different dose rate environments are described in details in the following sections. The photocurrent induced by transient radiation is a forcing function which drives the prompt change of the electrical parameters of the device. Degradation mechanism in schematic circuit of the operational amplifier through correlation of bipolar transistors response is discussed.

### EXPERIMENTAL SETUP

The intense pulsed X-ray facility used in this research is designed to deliver high transient radiation levels up to  $5 \times 10^{11}$  rad(Si)/s in a pulse with a full width at half maximum of 20 ns. Figure 1 shows the waveform of a pulsed X-ray, and the irradiation duration could be obtained by measuring the full width at half maximum of the pulse. The absorbed dose in the devices irradiated by X-rays is measured with thermoluminescence dosimeters. The dose rate is obtained by dividing the absorbed dose by the irradiation duration. The dose rates are varied by changing the distance between the devices and the flash X-ray facility, ranging from  $5.7 \times 10^9$  rad(Si)/s to  $1.1 \times 10^{11}$  rad(Si)/s in this experiment.

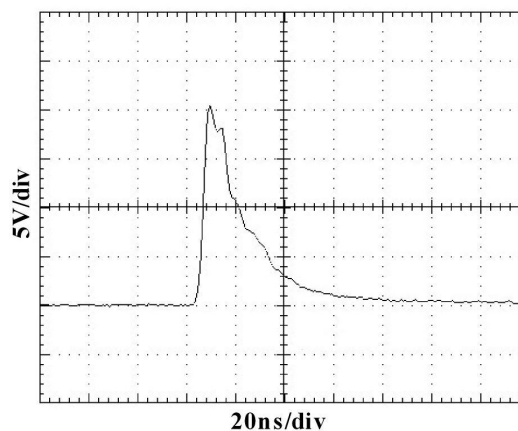


Figure 1: Waveform of a pulsed X-ray.

The test device  $\mu$ A741 used in the experiment is a member of bipolar operational amplifier family manufactured by Texas Instruments. It provides a high performance along with low power consumption, short circuit protection, offset voltage null capability, and large common mode and differential voltage ranges. In order to evaluate the effect of independent bias configuration during the irradiation, each device was respectively configured in voltage follower. Figure 2 shows the circuit configurations of the reversed-phase amplifier circuit. During the irradiation, the input power supply voltage  $V_{cc}$  was 15 V, and  $V_{ee}$  was -15 V. The test input was a sinusoidal signal with a frequency of 10 kHz and an amplitude of 1 V. The devices under test were enclosed in an aluminium case in order to provide effective shielding to electromagnetic coupling. All radiation tests were performed at the room temperature.

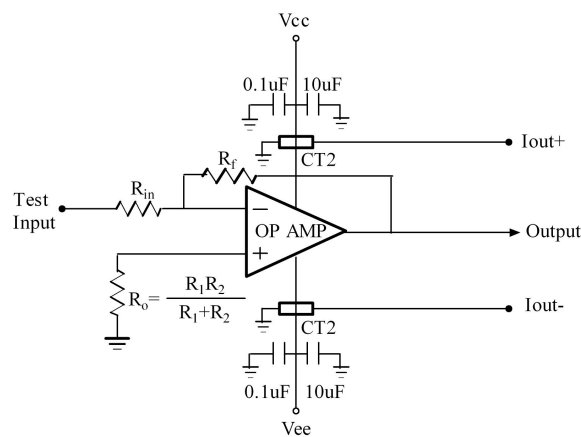


Figure 2: Bias configurations during irradiation.

**TEST RESULTS AND DISCUSSION**

The bipolar transistors in the  $\mu$ A741 operational amplifier are sensitive to transient ionizing response. However, unlike MOS devices, bipolar devices are unlikely to exhibit latchup when exposed to transient ionizing radiation [8]. The transient ionizing radiation effects of  $\mu$ A741 exhibit disturbance and subsequent recovery of output. Figure 3 shows the transient voltage disturbance at the output of the  $\mu$ A741 for two high dose-rate X-ray flash intensities. The shapes of the curves are specific to the pulsed X-ray radiation and could be divided into three main stages. The first stage is limited by the photocurrent induced by transient ionizing radiation, and the output drops from primary output level to a negative voltage level in a very short time. The second stage is response stage, and is limited by the open loop gain and the time constant of the amplifier. The disturbance amplitude is limited to about 15V saturation voltage, corresponding to the supply voltage level of the voltage source. The third stage is the recovery process, and the recovery time can be calculated by dividing the disturbance amplitude by the slew rate, which is  $0.6V/\mu s$  in the test. In addition, the disturbance duration increases with the increase of the dose rate of the pulsed X-ray radiation, as shown in Fig. 4.

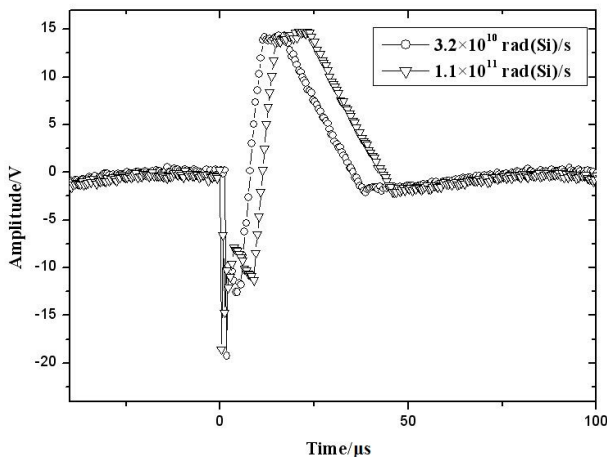


Figure 3: Transient response of output signal.

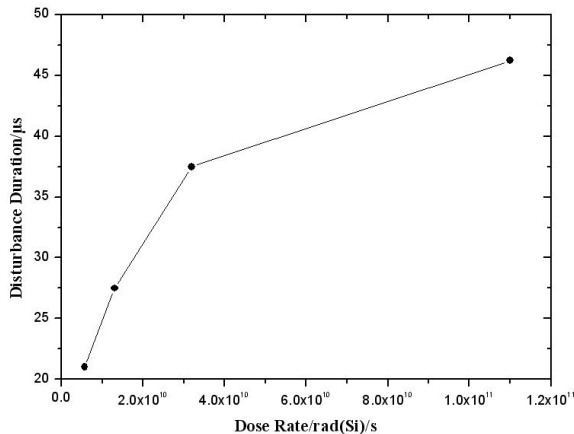


Figure 4: Disturbance duration versus dose rate.

Figure 5 shows the schematic representation of the  $\mu$ A741 operational amplifier at the transistor level. The  $\mu$ A741 could be divided into three different parts. The first part is a differential input pair, the second part is an intermediate inverting amplifier with a compensation capacitor, and the third part is a push-pull output. The  $\mu$ A741 is composed of 24 bipolar transistors, 11 resistors and 1 capacitor, and the transient radiation effects of bipolar transistors are responsible for the response of the operational amplifier. When the  $\mu$ A741 is exposed to X-ray flash radiation, hole-electron pairs will be created in the entire semiconductor material by raising the electrons from the valence to the conduction band. Then photocurrents form by the flow of carriers [9]. The primary photocurrents generated in the depleted layers of the emitter and the collector junctions of the bipolar transistors, are generally taken into account by additional current sources [10]. The output signal of the operational amplifier consists of the combined responses of all the bipolar transistors impacted.

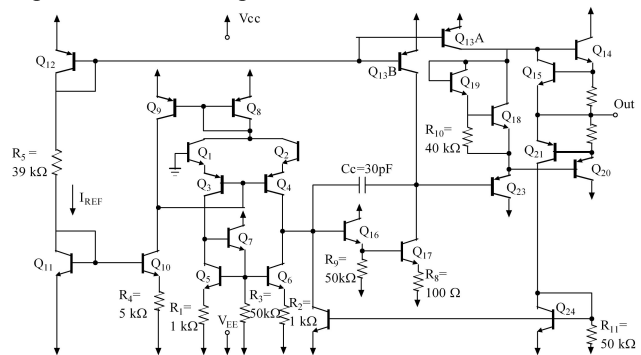


Figure 5: Schematic of uA741 operational amplifier.

**CONCLUSION**

In this paper, the transient ionizing radiation effect of a  $\mu$ A741 bipolar operational amplifier to pulsed X-rays was investigated. The experimental result indicates that the output response could be divided into three main stages. The first stage exhibits a transient decrease induced by primary photocurrents. The second stage displays a transient increase limited by the open loop gain and the time constant of the amplifier. The amplitude of the transient peak is not more than the supply voltage level of the voltage source. The third stage is a linear recovery process. The recovery time can be simply calculated by dividing the disturbance amplitude by the slew rate. The recovery time is of order of tens of microseconds, and has a positive correlation with the dose rate of the pulsed X-rays. The photocurrent in the bipolar transistors of the amplifier is the primal force function which drives the prompt change of the output. The additional current sources in the emitter and the collector junctions of the bipolar transistors can be regarded as the injection of transient response in the circuit. The method discussed in the paper can be used to analyze and predict the transient ionizing radiation effect of bipolar operational amplifiers.

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