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STUDY OF GAMMA-RAY EFFECTS ON RELAXATION OSCILLATOR BASED ON UNIJUNCTION TRANSISTOR

The object of this research is all the semiconductor unijunction transistor device (UJT) parameters that affect its operation as 1.67 kHz saw-tooth relaxation oscillator circuit under the influence of gamma-irradiation dose. Relaxation oscillators are widely used in function generators, electronic beepers, inverters, blinkers, and voltage-controlled oscillators. The properties of UJTs are like those of other semiconductor devices are greatly affect by irradiation. Its electrical characteristics and the output voltage waveforms of the relaxation oscillator circuit were investigated and plotted as a function of different gamma-dose levels. The type of semiconductor, the design of the device and the type of radiation are affected the magnitude of this change. Where, it is shown that increasing gamma dose up to 3.0 MGy leads, the peak voltage (V_P) to be decreased from 3.71 Volts down to 2.9 Volts, while the valley voltage (V_V) to be increases from 1.54 Volts up to 1.89 Volts, leading to a pronounced narrowing on the negative resistance region. As a result, both the output signal voltage amplitude and the frequency of the relaxation oscillator circuit were shown to be functions of the gamma-irradiation dose. Where, the initial values of the output signal voltage amplitude were reported to be 2.54 Volts decreased to the value of 2.13 Volts, while its frequency was 1.67 kHz increased up to 1.85 kHz, respectively, due to gamma-exposure levels up to 3.0 MGy using the GammaCell-220 (National Center for Radiation Research and Technology of Egypt).

Keywords: *semiconductor unijunction transistor device, relaxation oscillator, gamma-irradiation dose, gamma-exposure levels.*

1. Introduction

All devices utilized by humaneness are constantly exposed to different kinds of radiation originating from natural sources, however additionally from artificial manmade sources. Increasing the amount of integration of electronic components and miniaturization trends might have negative influence onto the components sensitivity to radiation. Radiation defects can also occur in a process of very large-scale integrated circuits fabrication, since the process often includes bombardment with high-energy ions and photons [1]. An electronic device which works in a radiation environment can present degradation due to the damage occurred in the semiconductor lattice [2].

The object of this research is all the semiconductor unijunction transistor device (UJT) parameters that affect its operation as 1.67 kHz saw-tooth relaxation oscillator circuit under the influence of gamma-irradiation dose.

The aim of this paper is to investigate the influence of gamma-irradiation up to 3.0 MGy on the operation of a 1.67 kHz saw-tooth relaxation oscillator circuit based on the UJT. In this concern, its emitter current-voltage (I_E–V_E), peak- and valley-voltages (V_P, V_V), inter-base resistance (R_{BB}) and inter-base voltage-current were investigated, as well, the electrical output parameters of the relaxation oscillator circuit.

2. Methods of research

2.1. Construction and characteristics of unijunction transistor. The UniJunction transistor (UJT), also called «double-base diode», was discovered by Jerry Suran in 1953 [3].

A unijunction transistor is a three-terminal device exhibiting a negative resistance region under certain conditions [4]. It is made of a lightly doped N-type silicon bar with two ohmic contacts called a base, to which a small amount of *p*-type material is diffused. The base terminals connected to each end are labeled B1 (base 1) and B2 (base 2). The P-material is the emitter and is labeled *E*. A power supply is connected across the base with the negative lead at B1 and the positive lead at B2 (Fig. 1) [5, 6]. The electrical equivalent circuit comprises a potential divider arrangement of two resistors R_{B1} and R_{B2} and a PN junction diode. Resistor R_{B1} represents the resistance of the base bar between B1 terminal and the PN junction and resistor R_{B2} represents the resistance of the base bar between B2 terminal and the PN junction. R_{B1} has been shown as a variable resistance as its value depends on the emitter current flowing through the PN junction when it is forward biased. For I_E=0, the total resistance of the base bar is termed as R_{BB} (R_{BB}=R_{B1}+R_{B2}). R_{BB} lies in the range of 4 KΩ to 10 KΩ. Another parameter defined for

a UJT is the intrinsic stand-off ratio denoted by η, where it is given by equation [7]:

$$\eta = R_{B1}/(R_{B1}+R_{B2}). \tag{1}$$
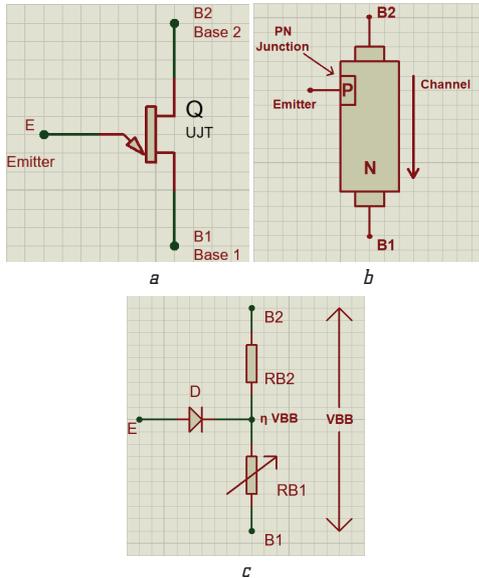
Fig. 1. Unijunction transistor: a — schematic symbol; b — structure diagram; c — equivalent circuit

2.2. Unijunction transistor relaxation oscillator. Oscillator is an essential block in communication and biomedical systems [8]. In this work the design of relaxation oscillator based on UJT is proposed using type 2N4870. Unijunction transistors are widely used in industries as a voltage controlled negative resistance relaxation oscillator [9] because of resistivity of UJT varies owing to carrier injection. Due to this, on the characteristics of unijunction transistor appears a domain with negative resistance, that is, under certain conditions, the voltage across the transistor can be reduced even with an increase in the output current through the load of transistor. Only the turn off transistor or opening the circuit can remove the input voltage [10].

The UJT has been mainly used as active device in relaxation oscillators because its current-voltage static characteristics have a portion in which the resistance is negative at the emitter terminal (E). The static emitter characteristic, i. e. the mathematical function modeling the relationship between the emitter voltage V_E and the emitter current I_E of a UJT at a given inter base voltage V_B is plotted in Fig. 2 [11].

A relaxation oscillator consists of an energy-storing element such as a capacitor and a nonlinear switching device such a Schmitt trigger comparator or negative resistance element connected by a feedback loop. The switching device periodically charges and discharges the energy stored in the capacitor, yielding abrupt changes in the output waveform [12]. The proposed relaxation oscillator circuit shown in Fig. 3, a consists of a UJT and a capacitor C which is charged through R as V is switched on. When the capacitor voltage V_C reaches in time t_s the value of V_P, the UJT fires and rapidly discharges C via B_1 till the voltage falls below the minimum value V_V. The device then cuts off and C starts to charge again. This cycle is repeated continuously thus generating a saw-tooth waveform across C. It should be noted that charging time constant of the capacitor for voltage V is $T=CR$ whereas

discharging time constant is $T_d=CR_{B1}$. The time required to charge up to V_P (called ramp rise time) is:

$$t_s=T\cdot\log_e(V-V_V)/(V-V_P). \tag{2}$$

Similarly, time required by the capacitor to discharge from V_P to V_V is:

$$t_d\cong T_d\cdot\log_e\cdot V_P/V_V. \tag{3}$$

The frequency of oscillation is given by [13]:

$$f=1/(t_s+t_d). \tag{4}$$
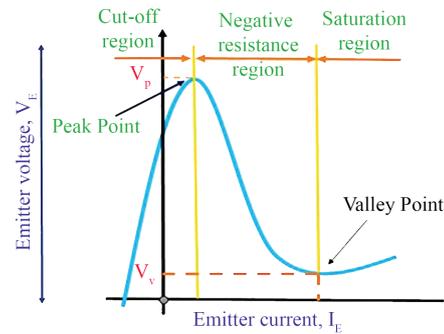
Fig. 2. Static Emitter Characteristic of the unijunction transistor
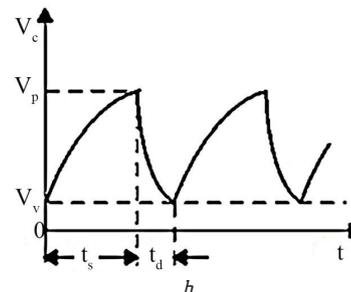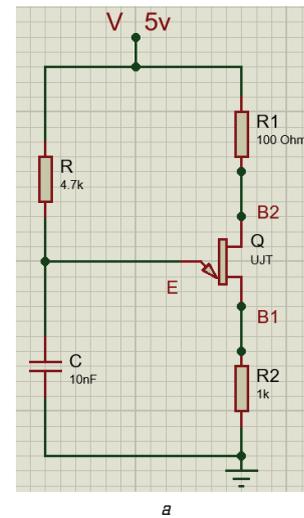
Fig. 3. A schematic representation of: a — unijunction transistor relaxation oscillator circuit; b — output saw-tooth waveform across C

Relaxation oscillators are generally used to create a low frequency signals for such applications as blinking lights and electronic beepers and clock signals in some digital circuits. The term relaxation oscillator is also applied to dynamical systems in many diverse areas of science that produce

a nonlinear oscillation that produces a non-sinusoidal repetitive output signal. And can be analyzed using the same mathematical model as electronic relaxation oscillators [14].

2.3. Experimental procedures. In order to obtain complete data about the effects of gamma-irradiation on Unijunction transistor (UJT) type 2N4870, as a relaxation oscillator circuit, its characteristics were plotted at different ascending gamma-doses up to 3.0 MGy using the GammaCell-220 (National Center for Radiation Research and Technology of Egypt) [15]. The electrical parameters based on I–V characteristics are investigated using the circuit shown in Fig. 4.
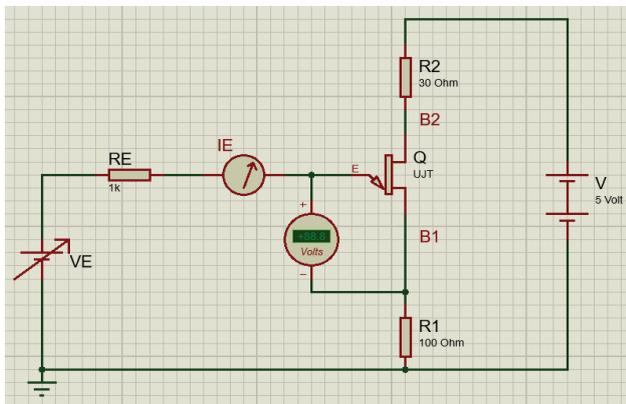
Fig. 4. Characterization circuit of unijunction transistors

In addition, a schematic representation of a driven UJT relaxation oscillator circuit is designed, constructed and implemented to produce a saw-tooth wave at a frequency of 1.67 kHz (Fig. 3), where waveforms were traced using a high-resolution oscilloscope «Tektronix Model TDS2024C (USA).

3. Research results and discussion

3.1. Radiation effect on the electrical parameters of UJT devices. The properties of UJTs are like those of other semiconductor devices which are greatly influenced by irradiation. So, it is expected that both branches of the (I_E–V_E) characteristic curves and electrical parameters of the devices change due to gamma-exposure dose levels. The magnitude of this change depends on the type of semiconductor, on the design of the device and the type of radiation. This part of the work is devoted to a discussion of permanent radiation effects on the tested UJT device type 2N4870 [16–18]. The negative resistance characteristic of the unijunction transistor depends on the conductivity modulation of a moderately high resistivity silicon bar by means of injected minority carriers from the rectifying emitter contact. It is, therefore, highly sensitive to radiation induced changes in minority carrier lifetime and resistivity. Fig. 5 shows a typical unijunction characteristic at constant value of V_{B2B1} equal 5 Volts. Gamma radiation will produce some displacement damage. However, gamma radiation can cause considerable ionization. The effects of ionization on unijunction devices would result primarily in an increase of surface leakage currents with some changes in V_V and V_p at high dose levels. It is clearly shown that, increasing gamma dose levels from 0.0 up to 3.0 MGy cause the peak voltage point (V_P) to decrease from 3.71 Volts down to 2.9 Volts (Fig. 6).

Gamma radiation data indicate that additional decreases in V_P may be incurred due to ionization effects. While the valley voltage (V_V) tends to increase from 1.54 Volts up to 1.89 Volts (Fig. 6), which leads to narrowing the negative resistance region. The peak voltage V_P is the most sensitive parameter as opposed to the valley voltage V_V for displacement damage [19].
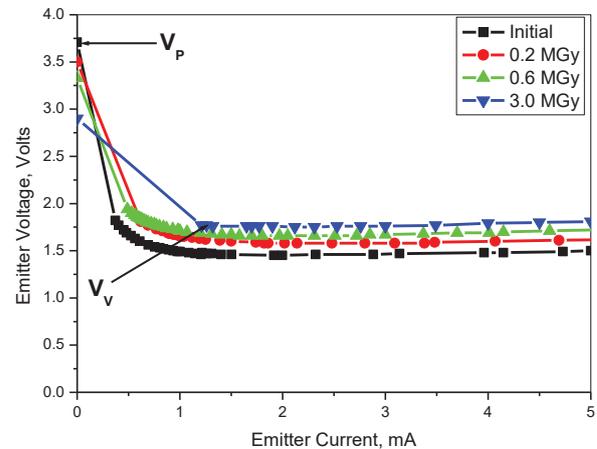
Fig. 5. Current-voltage characteristics of the unijunction transistor type 2N4870 under the influence of gamma exposure
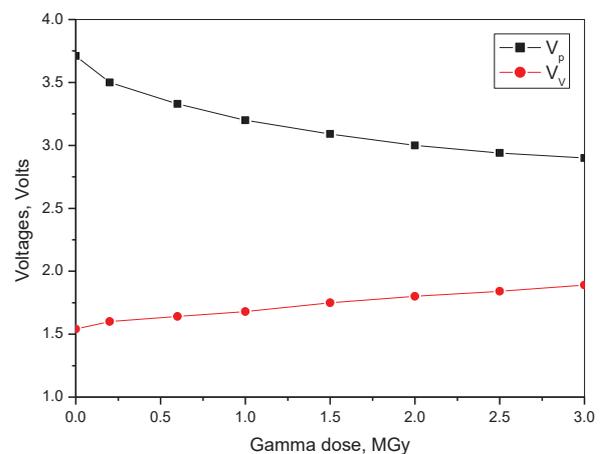
Fig. 6. Dependency of peak (V_P) and valley (V_V) voltages on gamma radiation

The effect of gamma dose on the inter-base characteristics which is considered to be the most important characteristics of the device is shown in Fig. 7. It is noticed that, the base current (I_B) increases linearly as a function of increasing both; inter-base voltage (Fig. 7, *a*) and gamma dose levels (Fig. 7, *b*). Where at a certain inter-base voltage value of 5.0 Volts, as an example, it is clearly shown that, I_B increase from 6.5 mA up to 8.5 mA.

The change of inter-base resistance in 2N4870 Si-UJT under irradiation of ^{60}Co γ-ray is provided. Through measurement, it was shown that the inter-base resistance decreased exponentially from 8.33 kΩ down to 6.5 kΩ and then constant as shown in Fig. 8. The obtained results were shown to be in excellent agreement with the previously published work on the field. This proves that the displacement effect is the main effect of inter-base resistance in Si-UJT irradiated by ^{60}Co γ-ray, but it lags behind the ionization effect from microanalysis of the interaction

between γ-ray and Si material. This is very important for the radiation hardened research [20].
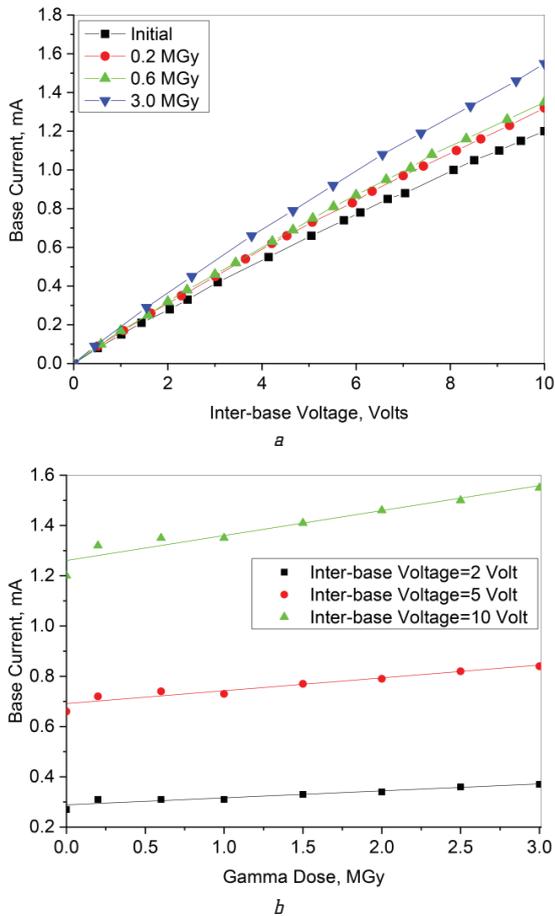
Fig. 7. Base current of the unijunction transistor type 2N4870 at $I_E = 0$ as a function of: a – inter-base voltage; b – gamma dose
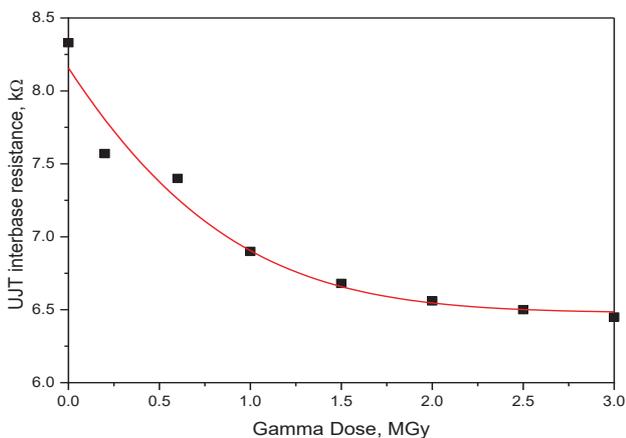
Fig. 8. Inter-base resistance variations as a function of gamma dose

3.2. Radiation effect on the relaxation oscillator circuit. The case of studying the characteristics of the proposed relaxation oscillator circuit under the influence of the gamma-dose levels is investigated and plotted in Figs. 9, 10.

Fig. 9 shows the output voltage waveforms of UJT relaxation oscillator circuit at the different gamma exposure. It is clearly shown that as the gamma-dose level increases, the following transient times of the pulse interval (t) and the capacitor charge (t_s) as well discharge (t_d) of the output

waveforms for the unijunction transistor relaxation oscillator decrease as shown in Fig. 9, 10. Where, values of 540, 534 and 6 µsec were recorded, at a gamma dose of 3.0 MGy, for t, t_s and t_d, respectively, although their initial values were 600, 590 and 10 µsec, respectively. Also, it is clearly shown that, the dependence of the signal amplitude values decreases from 2.54 V down to 2.13 V – by the ratio of 16 % – through the range from initial up to 3.0 MGy. While the frequency of the obtained output voltage increases from 1.67 kHz to 1.85 kHz – by the ratio of 11 % – with increasing gamma dose levels.
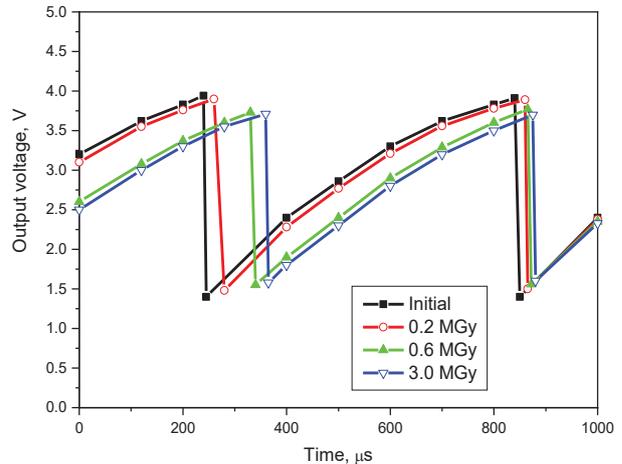
Fig. 9. Output voltage waveforms of unijunction transistor relaxation oscillator circuit at the different gamma exposure
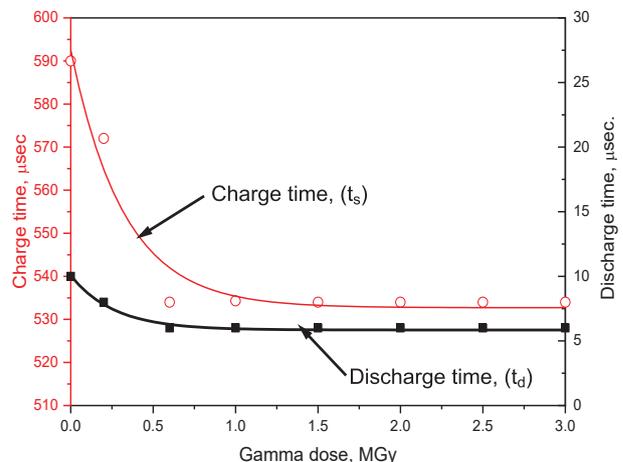
Fig. 10. Gamma radiation effect on the transient times of unijunction transistor relaxation oscillator

4. Conclusions

In this work, the effect of gamma-radiation exposure on the characteristics and the performance of 1.67 kHz a saw-tooth relaxation oscillator circuit including a unijunction transistor which, in turn, are used for timing purposes, were investigated experimentally. It is concluded that, the electrical properties of UJTs are greatly influenced by irradiation, like those of other semiconductor devices. The magnitude of this change depends on the type of semiconductor, on the design of the device and the type of radiation which are mainly attributed to the permanent radiation effect on the UJTs. Moreover, the proposed oscillator circuit output waveform shows both amplitude and frequency variations

as functions of change gamma dose exposure levels. Also, transient times of the pulse interval (t) and the capacitor charge (t_s) as well discharge (t_d) of the output waveforms for the unijunction transistor relaxation oscillator decrease as the gamma dose levels increase.

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