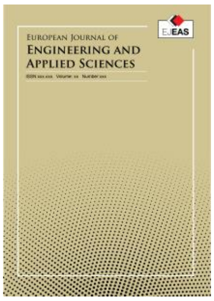
# European Journal of Engineering and Applied Sciences

ISSN: 2651-3412 (Print) & 2667-8454 (Online)
Journal homepage: http://dergipark.gov.tr/EJEAS
Published by Çorlu Faculty of Engineering, Tekirdağ Namık Kemal University

European J. Eng. App. Sci. 6(1), 1-7, 2023


*Research Article*

# An Optocoupler-based Biryukov Oscillator Design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*Geliş: 05.01.2023* *Kabul: 07.06.2023* *DOI: 10.55581/ejeas.1230140*



***Abstract:*** A Biryukov Equation is a special case of the Liénard equation. Liénard oscillators are commonly found in scientific literature and they have so many variants. The Biryukov Equation is used to model a set of damped oscillators. Unlike other Liénard oscillators, to the best of our knowledge, there is not a Biryukov oscillator that is experimentally examined in the literature, yet. In this study, a Biryukov oscillator is made using a microcontroller-controlled hand-made optocoupler, a negative impedance converter, and a gyrator. An STM32F070RB is used for the required switching. The oscillator's operation has been examined experimentally. The optocoupler made of an LDR and a LED placed in a box allows the resistive switching required by a Biryukov oscillator to occur. The experimental results show that the circuit operates as an oscillator and performs well. It is also shown that an underdamped or an overdamped Biryukov oscillator can be made by varying circuit parameters.



***Keywords:*** *Biryukov Equation, Biryukov Oscillator, Circuit Dynamics*


### Bir Optokuplör Tabanlı Biryukov Osilatörü Tasarımı


***Öz:*** Biryukov Denklemi, Liénard denkleminin özel bir halidir. Liénard osilatörleri bilimsel literatürde yaygın olarak bulunur ve pek çok çeşidi vardır. Biryukov Denklemi, sönümlü osilatörlerin bir setini modellemek için kullanılır. Bildiğimiz kadarıyla diğer Liénard osilatörlerinden farklı olarak literatürde henüz deneysel olarak incelenen bir Biryukov osilatörü yoktur. Bu çalışmada, mikrodenetleyici kontrollü el yapımı bir optokuplör, bir negatif empedans dönüştürücü ve bir jiratör kullanılarak bir Biryukov osilatörü yapılmıştır. Gerekli anahtarlama için bir STM32F070RB kullanılmıştır. Bu osilatörün çalışması deneysel olarak incelenmiştir. Kutuya yerleştirilmiş bir LDR ve bir LED'den oluşan optokuplör, Biryukov osilatörünün ihtiyaç duyduğu dirençli anahtarlamanın gerçekleşmesini sağlar. Deneysel sonuçlar, devrenin bir osilatör olarak çalıştığını ve iyi performans gösterdiğini göstermektedir. Ayrıca, devre parametrelerini değiştirerek, düşük sönümlemeli veya aşırı sönümlemeli Biryukov osilatörünün yapılabileceği gösterilmiştir.



***Anahtar Kelimeler:*** *Biryukov Denklemi, Biryukov Osilatörü, Devre Dinamikleri*


## 1. Introduction

Liénard's equations were proposed by Alfred-Marie Liénard in 1928 to model a set of oscillators [1]. Van der Pol oscillators are a subset of the Liénard equations [2-5]. Van der Pol oscillator and the Liénard Oscillator are historically significant [2, 6]. Liénard and Van der Pol oscillators are commonly used for chaos studies [7-9]. A Liénard Oscillator or a Van der Pol oscillator can be made using various circuit elements such as diodes and lasers [1, 8-12]. Liénard Oscillator circuit has numerous circuit variations. An optical resonance tunneling diode-based oscillator can also be modeled with the Liénard


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equation [10]. In [11], a Van der Pol oscillator makes use of anti-parallel Shottky-diode strings. In [12], a Liénard oscillator is made with a nonlinear resistance circuit employing a Schottky-diode bridge fed JFET. An FPGA-based chaotic van der pol oscillator is made in [13] but FPGAs are still expensive devices. A microcontroller-based Liénard oscillator is made in [14]. The Biryukov equation named after Vadim Biryukov is a non-linear second-order differential equation used to model some damped oscillators (Biryukov oscillators) and is also one of the special cases of the Liénard equation [15, 16]. The behavior of limit cycles of the Biryukov equation, considering its applicability has been examined in [17]. The Biryukov oscillator has only been examined with simulations and analytically. To the best of our knowledge, a Biryukov Oscillator has not been made in the literature yet. In this study, a Biryukov Oscillator has been designed and realized for the first time in the literature. Its nonlinear resistor is made using a hand-made optocoupler inspired by [18]. The optocoupler is controlled with a microcontroller. An STM32F070RB is chosen for that purpose. The circuit simulations are done in Matlab™. Then, the circuit is assembled, and its experimental waveforms are acquired. The voltage and the switching function of the Biryukov Oscillator circuit are presented.

The paper is arranged as follows. The second section gives basic information on the Biryukov Equation and the Biryukov Oscillator. In the third section, the proposed Biryukov Oscillator circuit is given. In the fourth section, the switching algorithm of the LED is presented. In the fifth section, Matlab simulations of the Biryukov Oscillator are given. In the sixth section, the experimental results of the circuit are given. The paper is finished with the conclusion section.

## 2. Biryukov Equation and the Biryukov Oscillator

In this section, the Biryukov Equation is given and briefly explained. The Biryukov equation has been proposed by Vadim Biryukov as

$$\frac{d^2y}{dt^2}+f(y)\frac{dy}{dt}+y=0 \tag{1}$$

where $y$ is a state variable and $f(y)$ is a piecewise constant function that is positive except for small $y$ and it is expressed as

$$f(y)=\begin{cases}-F, |y|\leq Y_0 \\ F, |y|>Y_0\end{cases} \tag{2}$$

where $F$ and $Y_0$ are positive constants ($F>0$ and $Y_0>0$).

$f(y)$ is an even function since $f(y)=f(-y)$. Eq. (1) is a special case of the Liénard equation; it describes the auto-oscillations dependent on Eq. (2).

The generic Liénard oscillator is made of an inductor, a capacitor, and a nonlinear resistor. The generic Liénard oscillator is shown in Figure 1 [12]. Since the Biryukov equation is also a special case of the Liénard equation, it is also true that the Biryukov oscillator also consists of an inductor, a capacitor, and a nonlinear resistor.

The constitutive equations of the capacitor, the inductor, and the nonlinear resistor are given as

$$i_C(t)=C\frac{dv_C(t)}{dt}, \tag{3}$$

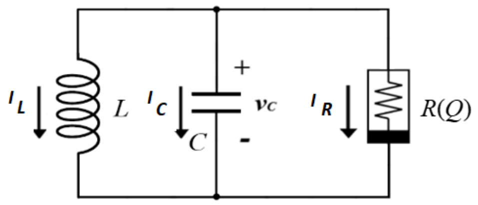



***Fig. 1.*** *The generic Liénard oscillator [12].*

$$v_L(t)=L\frac{di_L(t)}{dt}, \tag{4}$$

and

$$v_R(t)=Ri_R(t). \tag{5}$$

Using Kirchhoff's laws, these following equations can be written:

$$v_R(t)=v_C(t)=v_L(t). \tag{6}$$

and

$$i_R(t)+i_C(t)+i_L(t)=0 \tag{7}$$

By combining Eq.s (3)-(7), the capacitor voltage of the circuit is described as

$$LC\frac{d^2v_C(t)}{dt^2}+\frac{L}{R(Q)}\frac{dv_C(t)}{dt}+v_C(t)=0 \tag{8}$$

or

$$\frac{d^2v_C(t)}{dt^2}+\frac{1}{R(Q)C}\frac{dv_C(t)}{dt}+\frac{1}{LC}v_C(t)=0 \tag{9}$$

where $v_C(t)$ is the oscillator or the capacitor voltage, $L$ is the inductance of the oscillator, $R(Q)$ is the resistance of the oscillator, and C is the capacitance of the oscillator.

We need to obtain a nonlinear resistor. Comparing Eq. (2) and Eq. (9), it is seen that $f(y)$ must satisfy

$$f(y)=\frac{1}{R(Q)C} \tag{10}$$

A nonlinear resistor, whose nonlinear resistance is an even function of voltage, must be used in the Liénard Oscillator and also in the Biryukov oscillator [12]. However, the nonlinear resistor in the Biryukov oscillator can be obtained by switching an active resistor $-R$ and passive resistor $R$ periodically as shown in Figure 2. Therefore, the mechanical switches $S_1$ and $S_2$ must be controlled to obtain the desired resistance $R(Q)$. The switching function $Q$ can be expressed as

$$Q = \begin{cases} 1 \quad , \quad |v_C(t)| \leq v_{C0} \\ 0 \quad , \quad |v_C(t)| > v_{C0} \end{cases} \tag{11}$$

where $v_{C0}$ is a positive voltage value.

When the switch S is on, *Q*=1 and vice versa. The resistance value of *R(Q)* as a function of the switching function is written as

$$(Q) = \frac{1}{f(y)C} = \begin{cases} -\frac{1}{F}, |v_C(t)| \leq v_{C0} \\ \frac{1}{F}, |v_C(t)| > v_{C0} \end{cases} = \begin{cases} -\frac{1}{F}, Q = 1 \\ \frac{1}{F}, Q = 0 \end{cases} \tag{12}$$

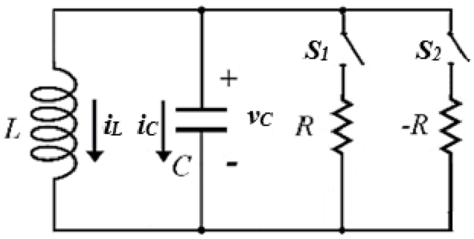



***Fig. 2.*** *A Biryukov oscillator*

## 3. The Proposed Biryukov Oscillator Topology

The proposed Biryukov oscillator circuit and its components are explained in this section.

### 3.1. The Optocoupler-based Equivalent Resistor of the Biryukov Oscillator

In [18], a hand-made optocoupler is used to obtain an even resistance function. Such an optocoupler is also used in this study. The circuit schema of the optocoupler and its arrangement in the box are shown in Figure 3. A LED and an LDR are placed in a box to make the optocoupler and it is also wrapped with black bandages to eliminate the effect of the ambient light or the undesired light sources as shown in Figure 3.a. More information about how to design such an optocoupler can be found in [18]. The photographs of the system are given in Figure 3.b. The LDR resistance $R_{LDR}$ is only a function of the light provided by the LED. $R_{LDR}$ takes its minimum value when the LED is on and its resistance is maximum when the LED is off. To make a fine-tuning, the resistance value of the resistor $R_1$ is adjusted in the experiments so that the LDR resistance can be adjusted as desired for a better performance.

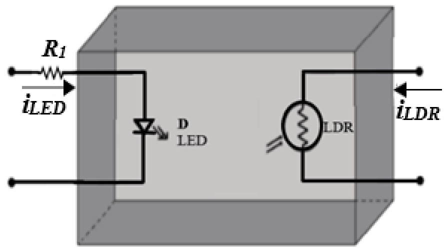
The experimental setup in Figure 4 is used to measure the resistance value of the LDR resistor depending on whether the LED is on or off. LED is controlled with the STM32F070RB microcontroller. Using an ohmmeter, the LDR resistance designated as $R_{on}$ is measured as 136 $\Omega$ when the LED is on and the LDR resistance designated as $R_{off}$ is measured as 377 $k\Omega$ when the LED is off.

The switching function Q is defined as equal to 1 if the LED is on. The switching function Q is equal to 0 if the LED is off, The LDR resistance can be described as

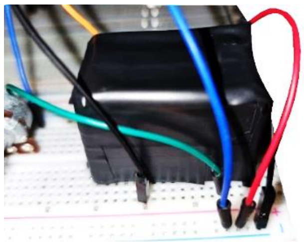
$$R_{LDR}(Q) = \begin{cases} R_{on}, |v_C(t)| \leq v_{C0} \\ R_{off}, |v_C(t)| > v_{C0} \end{cases} = \begin{cases} R_{on}, Q = 1 \\ R_{off}, Q = 0 \end{cases} \tag{13}$$

It must be provided that

$$R_{off} \gg R_{on} \tag{14}$$




(a)



(b)

***Fig. 3.*** *a) The topology and the circuit of the optocoupler and b) the external view of the optocoupler box made.*

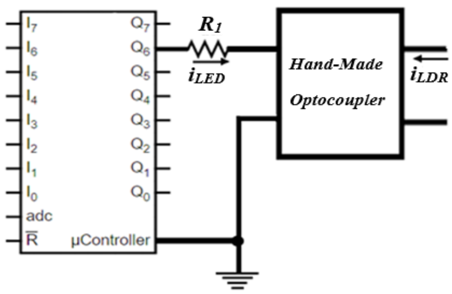



***Fig. 4.*** *Optocoupler test circuit.*

### 3.2 The Negative Resistance Circuit

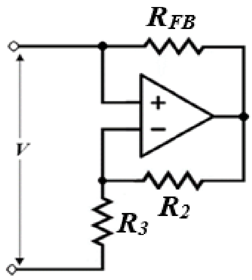
An opamp-based negative resistor circuit is shown in Figure 5.a. $R_{FB}$ of the negative resistor circuit is replaced with the optocoupler circuit to obtain the nonlinear resistor of the Biryukov Oscillator as shown in Figure 5.b. Then, the negative resistor's resistance is given as

$$R_{neg} = -R_3 R_{LDR} / R_2 \tag{15}$$

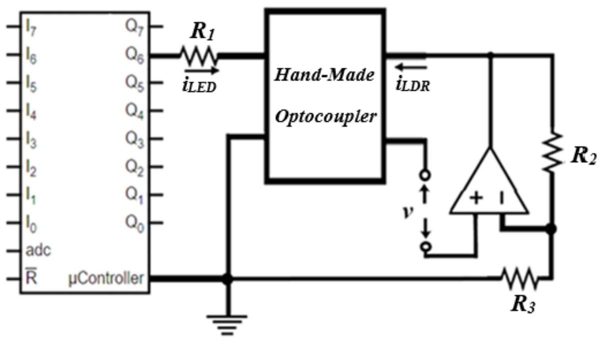
If $R_3 = R_2$, the negative resistor's resistance turns into

$$R_{neg} = -R_{LDR} \quad (16)$$

A microcontroller is used to control the resistance of the LDR in the optocoupler of the oscillator by turning on and off the LED connected to its digital output. The negative resistor circuit is connected in parallel with an LTI resistor whose resistance is equal to $R_p$=2$R_{on}$ to obtain the nonlinear resistor of the Biryukov oscillator shown in Figure 8.




a)




b)

***Fig. 5.*** *a) The opamp-based negative resistor circuit and b) The modified negative resistor circuit of the oscillator.*

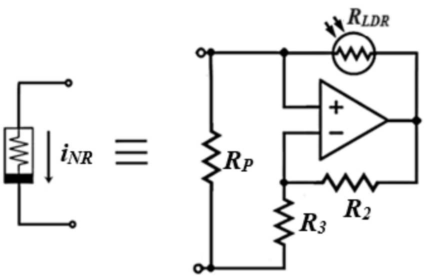



***Fig. 6.*** *The nonlinear resistor of the Biryukov oscillator*

If there is no light:

$$R_{LDR} = R_{off} = 377\ k\Omega \quad (17)$$

Considering the LDR parameters, the following is true:

$$R_{off} \gg R_p \quad (18)$$

If the LED of the optocoupler is off or the LDR is not illuminated, the equivalent resistance of the nonlinear resistor of the Biryukov oscillator can be approximated as follows.

$$R(Q) = R_{ON} = \frac{R_p \cdot (-R_{LDR})}{R_p - R_{LDR}} \cong \frac{R_p \cdot (-R_{max})}{-R_{max}} \cong R_p \quad (19)$$

If the LED of the optocoupler is turned on or the LDR is illuminated:

$$R(Q) = R_{OFF} = \frac{R_p \cdot (-R_{LDR})}{R_p - R_{LDR}} = \frac{2R_{on} \cdot (-R_{on})}{2R_{on} - R_{on}} = -2R_{on} = -R_p \quad (20)$$

### 3.3. The Gyrator Circuit

Gyrator circuits are commonly used to make adjustable inductors [19]. In this study, A gyrator circuit is also used to obtain the required inductor of the Biryukov oscillator as shown in Figure 7. In periodic steady-state under sinusoidal excitation, its input impedance is given as

$$Z_{in} = (R_L + j\omega R_L R_G C)//\left(R_G + \frac{1}{j\omega C}\right) \quad (21)$$

$R_G$ is chosen sufficiently large such that the $RC$ circuit's impact on the input impedance is negligible. Then, the input impedance of the gyrator is given as

$$Z_{in} = R_L + j\omega R_L R_G C = R_L + j\omega L \quad (22)$$

Then, its input inductance is:

$$L = R_L R_G C \quad (23)$$

If the resistance of the resistor $R_L$ *is* chosen low enough, the gyrator can be assumed to behave as if an ideal inductor. In this study, $R_L$ is taken to be 110 $\Omega$ which is much lower than the minimum resistance of the LDR, $R_{on}$. The resistance value of the resistor $R_G$ is adjusted using a potentiometer.

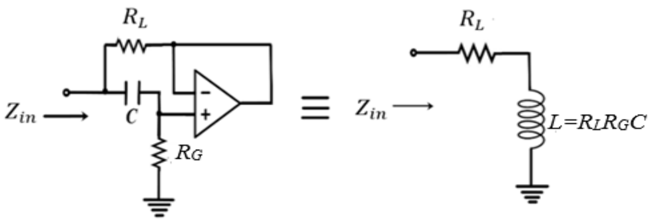



***Fig. 7.*** *The Gyrator circuit behaving as the inductor of the oscillator.*

### 3.4 The Microcontroller-based Voltage Reading and Optocoupler Control Circuit

The circuit schematic of the microcontroller-controlled Biryukov oscillator circuit is shown in Figure 8. It consists of an STM32F070RB microcontroller, the nonlinear resistor made in the previous section, and the gyrator. The microcontroller controls the LED to adjust the LDR resistance. Adjusting the LDR resistance by turning on and off the LED of the optocoupler results in the oscillation of the circuit. An opamp-based summing circuit that is shown in Figure 8 and has the resistors $R_4$, $R_5$ $R_6$, and $R_7$, is used to add up the oscillator voltage with 1.5 V DC voltage before reading it with one of the ADCs of the microcontroller since the microcontroller cannot read negative voltages. This process provides the proper voltage range for the microcontroller`s ADC input. The Microcontroller`s ADC resolution is set to 12-bit and its operating frequency is set to 48 MHz.

## 4. The Switching Program Algorithm

The microcontroller is programmed in C. The algorithm of the microcontroller program is given as the flowchart shown in Figure 9. The microcontroller reads the capacitor voltage $v_C(t)$ and then compares it with $v_{C0}$. If the absolute value of $v_C(t)$ is less than $v_{C0}$, the LED is turned on and vice versa. This is repeated as an infinite loop.

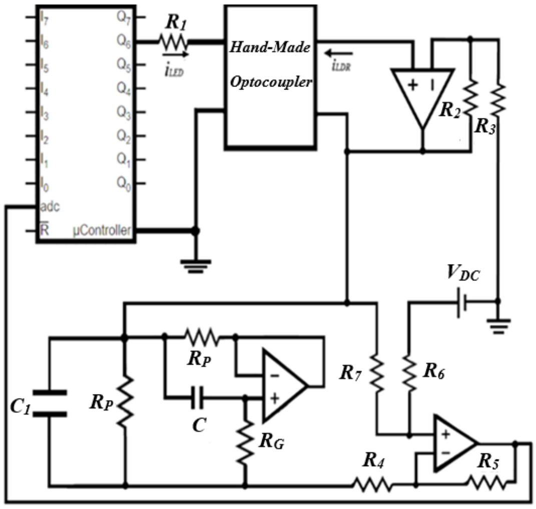



***Fig. 8.*** *The Biryukov oscillator circuit schematic*

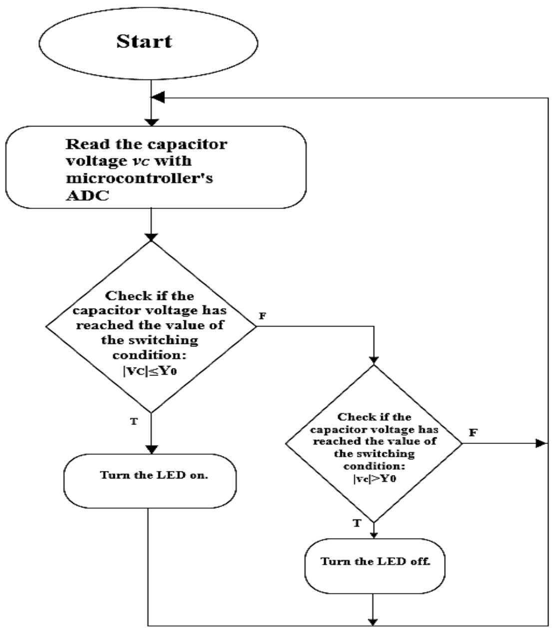



***Fig. 9.*** *The flowchart of the Biryukov oscillator program.*

## 5. Simulation Results of the Biryukov Oscillator

A simulation program for the oscillator circuit shown in Figure 2 is written in Matlab. The circuit is simulated for two different $F$ values. The Biryukov oscillator voltage $v_C(t)$ is plotted and shown in Figure 11. Both of the waveforms in the periodic steady-state have half-wave symmetry as can be seen in Figure 10.

For a lower value of $F$ such as 0.01, the Biryukov oscillator voltage resembles a sinusoidal signal more as shown in Figure 10.a since the oscillator circuit has a lower equivalent resistance $R_p$ and operates as an almost ideal $L$-$C$ tank circuit. However, it has harmonics.

For a higher value of $F$ such as 4, the capacitor voltage resembles a relaxation oscillator or a sawtooth oscillator signal more as shown in Figure 10.b. since the circuit has a higher resistance $R_p$. In this case, its harmonic content is much higher.

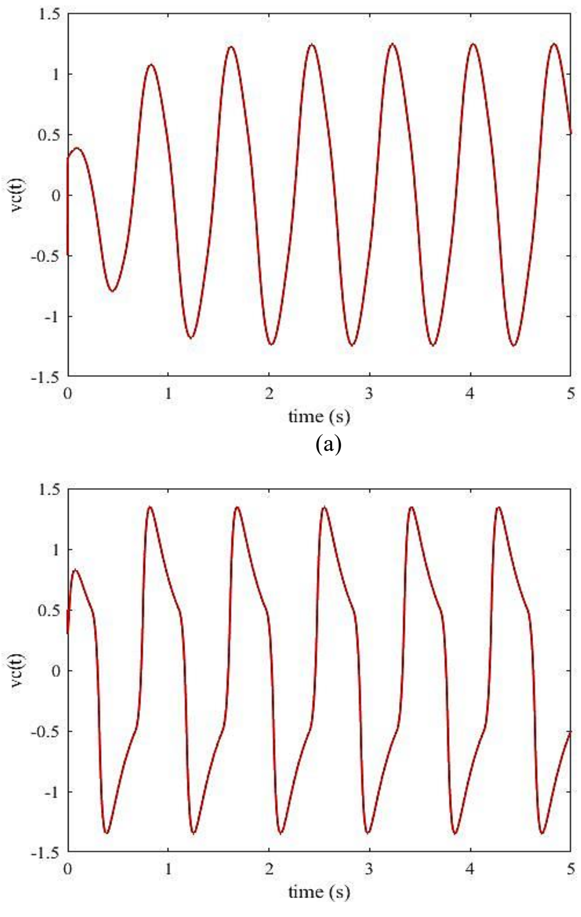



***Fig. 10.*** *The simulated Biryukov oscillator or the capacitor voltage $v_C(t)$ for a) F=0.01 and b) F=4*

## 6. Experimental Results of the Biryukov Oscillator

In this section, the experimental results of the Biryukov oscillator circuit are given. The Biryukov oscillator circuit is assembled on a protoboard and is also shown in Figure 11. In order to generate the experimental oscillator waveforms, the circuit parameters given in Table 1 is used. The resistance of the resistor $R_p$ is adjusted using a potentiometer and its final value is given in Table 1. The experimental waveforms are acquired by the STM32CubeMonitor that is a monitor program installed on a PC. The application helps to fine-tune and diagnose STM32 applications at run-time by reading and visualizing their variables in real-time. The STM CubeMonitor which interfaces with the microcontroller STM32F070RB in real time and shows the variation of the capacitor voltage variable $v_C(t)$ in this study. The microcontroller is connected with the PC via usb 3.0 and the monitor program operates at 4.6 MHz frequency. The acquired experimental time domain waveforms are shown in Figure 12. The capacitor voltages have 1.5 Volt DC offset since the oscillator waveform is summed with a 1.5 Volt DC voltage as can be seen in Figure 12. The experimental results shown in Figure 12 resemble the simulated ones given in Figure 10 and it can be said that the Biryukov Oscillator can produce the desired state variable $v_C(t)$ and performs well. An underdamped and an overdamped Biryukov oscillator can be made by varying circuit parameters as shown in Figure 12 respectively.

**Table 1** Circuit parameters.

| | Circuit Parameters for the waveform given in Figure 13.a | Circuit Parameters for the waveform given in Figure 13.b |
|---|---|---|
| $R_p$ | 4.2 $k\Omega$ | 3.8 $k\Omega$ |
| $R_{LDR}$ | 2.32 $k\Omega$ | 1.7 $k\Omega$ |
| $C_1$ | 2.2 $\mu F$ | 2.2 $\mu F$ |
| $C$ | 10 $\mu F$ | 10 $\mu F$ |
| $R_L$ | 110 $\Omega$ | 110 $\Omega$ |
| $R_G$ | 8.279 $k\Omega$ | 39 $k\Omega$ |
| $R_2$ | 51 $k\Omega$ | 51 $k\Omega$ |
| $R_3$ | 51 $k\Omega$ | 51 $k\Omega$ |
| $R_4$ | 22 $k\Omega$ | 22 $k\Omega$ |
| $R_5$ | 22 $k\Omega$ | 22 $k\Omega$ |
| $R_6$ | 18 $k\Omega$ | 18 $k\Omega$ |
| $R_7$ | 18 $k\Omega$ | 18 $k\Omega$ |

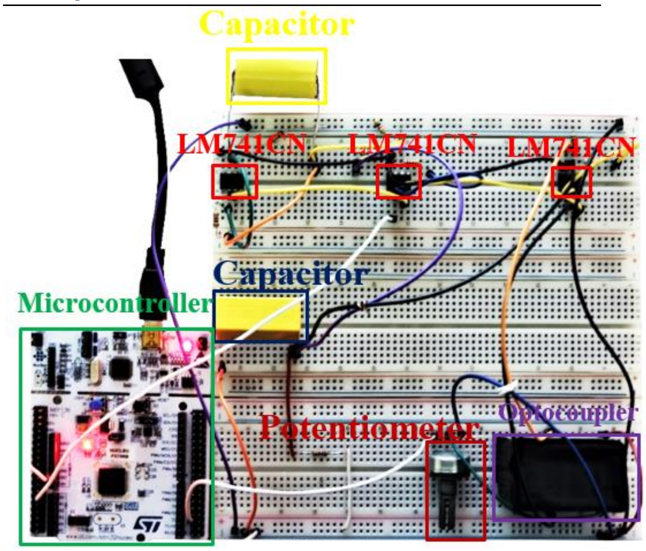
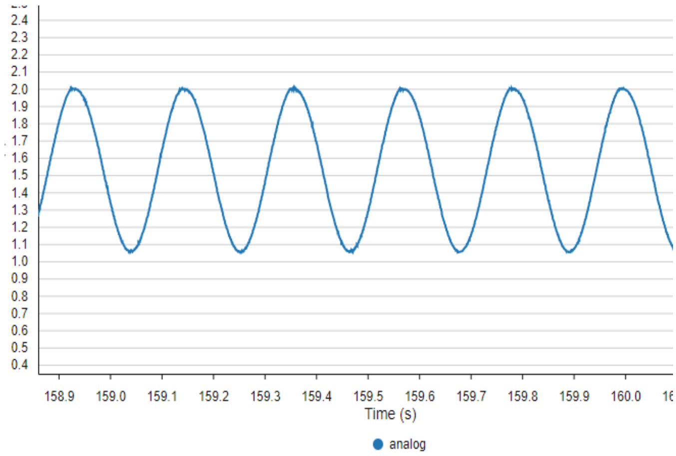
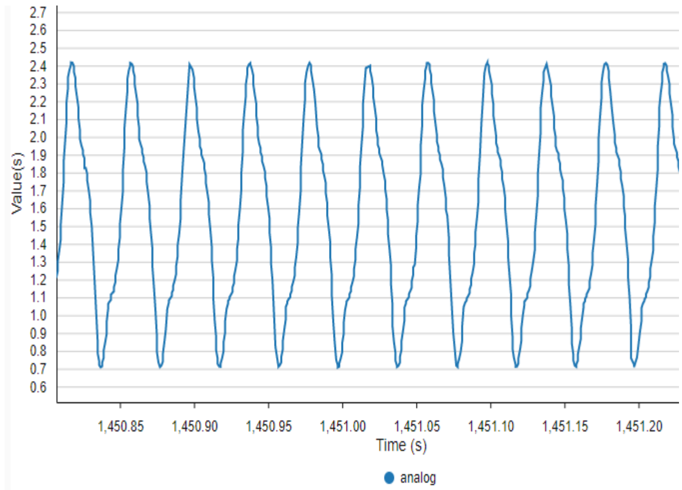



***Fig. 11.*** *Photograph of the implemented Biryukov oscillator circuit.*




(a)




(b)

***Fig. 12.*** *The experimental Biryukov Oscillator voltage $v_C(t)$ for a) F=0.01 (the underdamped case) and b) F=4 (the overdamped case)*

## 7. Conclusions

In this paper, a microcontroller-based Biryukov Oscillator is made for the first time in the literature. In this work, a cheap and easy-to-use STM32F070RB microcontroller is preferred for this purpose. With one of its ADCs, it reads the capacitor voltage and controls the LED via its digital output. To the best of our knowledge, the Biryukov oscillator signal has been obtained in analog form for the first time in the literature. The experiments have confirmed that the circuit operates as a Biryukov Oscillator. It is also shown that it is possible to obtain an underdamped and an overdamped Biryukov oscillator by varying the oscillator parameters. As a future work, by modifying the light intensity produced by the LED controlled by the microcontroller, new types of oscillator waveforms can be obtained. The Biryukov oscillator circuit can also be employed in circuit laboratories for educational purposes. The coupling of the Van der Pol or Liénard Oscillators is a hot research topic and the coupling of a Biryukov oscillator with the other oscillators can also be examined in the future.

## Author Contribution

Formal analysis –Reşat Mutlu (RM); Investigation – RM; Experimental Performance – Mendi Arapi (MA); Data

Collection RM– MA; Processing – MA; Literature review – RM; Writing – RM, MA; Review and editing – RM, MA;

## Declaration of Competing Interest

The authors declared no conflicts of interest with respect to the research, authorship, and/or publication of this article.

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