IMPLEMENTATION AND STUDY OF CHUA'S CIRCUIT

DEPARTMENT OF PHYSICS
BHARATA MATA COLLEGE,
THRIKKAKARA ,KOCHI

Bsc PHYSICS MODEL 1

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Implementation and Study of Chua's Circuit

PROJECT REPORT

submitted In partial fulfillment of requirements for the award of the degree of

BACHELOR OF SCIENCE IN PHYSICS

(Mode I)

FOR GOD & COUNTRY

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BHARATA MATA COLLEGE, THRIKKAKARA , KOCHI-21

OF

MAHATMA GANDHI UNIVERSITY KOTTAYAM

MAHATMA GANDHI UNIVERSITY, KOTTAYAM

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BATCH 2021-2024

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DEPARTMENT OF PHYSICS

CERTIFICATE

Certificate that this document titled “” Implementation and study of chua’s circuit “is a bona-fide project report presented by Maalavigaa Rajesh,Lenet Joseph,Vishnu M sasi (university registration number:210021034411,210021034426,210021034431) of sixth semester BSc Physics, model I submitted In partial fulfillment of the requirements for the award of the degree of Bachelor Of Science In physics of the Mahatma Gandhi university, Kottayam during the academic year 2021-2024.

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Internal Examiner **External Examiner**

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Project report submitted to the

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DEPARTMENT OF PHYSICS

BHARATA MATA COLLEGE, THRIKKAKARA

(2021-2024)

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DECLARATION

I hereby declare that this project report entitled **"Implementation and study of chua's circuit "** is based on the original work carried out by me under the supervision of Dr.Lini Devassy in the department of Physics, Bharata Mata College, Thrikkakkara.

PLACE: THRIKKAKARA

DATE:

ACKNOWLEDGEMENT

I consider myself very fortunate to have had the support and direction of so many people throughout this project, as their contributions were crucial to its development and ultimate result of my work. Whatever I have done is only due to such guidance and assistance and I would not forget to thank them.All of my accomplishments are solely a result of their advice and help, and I will always be grateful.

First of all, I would like to thank God almighty for his divine grace and blessings throughout the course of this work.

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I owe my profound gratitude to our project guide Dr.Lini Devassy who took keen interest in the project work and guided us all along, till the completion of our project by providing all the necessary information for developing a good system and I would like to extend my sincere gratitude to all my faculties for their support and guidance for the completion of my work.

I would also like to extend my sincere thanks to all my friends and family for their whole hearted support

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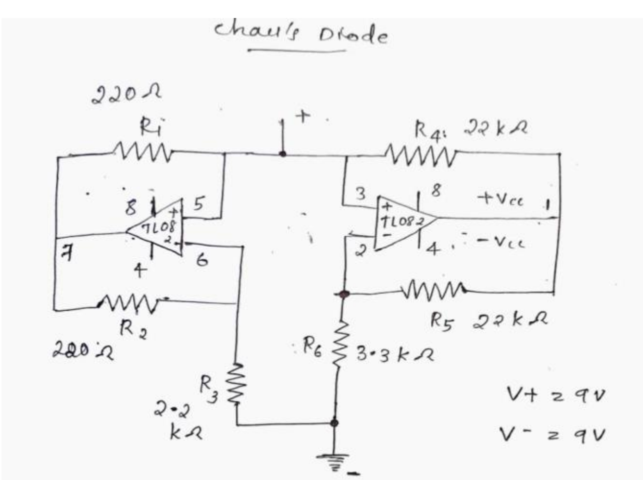
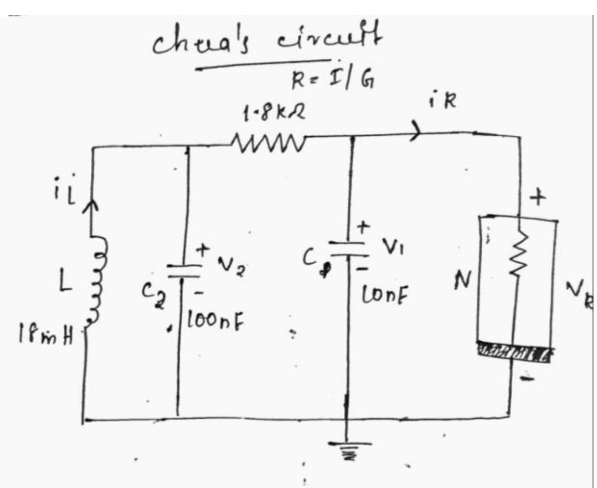
CHAPTER 1

INTRODUCTION

The Chua circuit is a remarkable electrical design that is renowned for its chaotic behaviour tendencies. Created in the year 1983, this circuit is said to be one of the turning points in the realm of nonlinear dynamics and chaos theory. Despite its straightforward structure that consisting few parts, it has a broad spectrum of properties. With elements like resistors, capacitors and operational amplifiers combined together, the Chua circuit shows the world that deterministic systems can be unpredictable as well as seemly random. Such a circuit is built around a component known as Chua diode that makes it non-linear in behavior due to the fact that the current-voltage relation across it follows piece-wise linear pattern but not linearly (Lev). The nonlinear resistor whose voltage- current characteristic is an example of piecewise-linear curve thus provides such nonlinearity needed for creating chaos within this system.





Alongside the Chua diode, the circuit comprises two capacitors and three operational amplifiers interconnected in a specific configuration.

The behavior of the Chua circuit is governed by a set of nonlinear differential equations.

A nonlinear system refers to systems that their nonlinear equations govern how they evolve over time; that is the equations describing its properties involve the system's dynamical variables in a nonlinear manner. This definition can be made clearer using two examples taken from elementary physics. One system linear while the other non-linear. In classical mechanics, here is how one describes the motion of a point mass particle of mass m responding only to forces acting along x-direction but constrained within x direction alone and following Newton's second law of motion

$$F_x(x, t) = ma = m\,(d_2x/dt_2) \qquad (1.1)$$

For a point mass subject to the force from an ideal spring, the force is given by

$$F_x(x) = -kx \qquad (1.2)$$

Here x is the displacement of the spring from its equilibrium position and k is the spring constant.

Combining the equation (1.1) and (1.2), we find the time evolution equation for the position of the particle:

$$d_2x/\,dt\,_2 = -(k/m)x \qquad (1.3)$$

This equation is linear in x and its second derivative of x. Thus what is described above is a linear system.

Suppose the force has a more complicated dependence.
For example if $F_x = bx^2$,
Then the time evolution equations is

$$d_2x / dt_2 = (b/m)x^2 \qquad (1.4)$$

The system is nonlinear. According to the condition of linearity, if g(x, t) and h(x, t) which are solutions of the time evolution equation of a system, are linearly independent, then cg(x, t) + dh(x, t) is also a solution where c and d are constants. Nonlinear dynamics deals with nonlinear systems where their evolution equations are also nonlinear. Small change in parameter may result in abrupt changes in qualitative or quantitative characteristics of the system in case of nonlinearity. Thus, for some particular value it may display periodic behavior; while for another such period will not distinguish from a small variation at all. To some level, almost all systems do not conform to linear expectations. Such sudden, dramatic shifts may lead to chaos in nonlinear systems.

One of the most captivating aspects of the Chua circuit is its ability to produce chaotic oscillations characterized by irregular patterns and seemingly random fluctuations. These chaotic oscillations manifest as voltage waveforms that display a distinctive “double-scroll” shape when plotted in phase space.

History and background:

Origins

Electrical engineer, Professor Leon Chua, introduced the Chua circuit in the 1960s as were developed at the University of California, Berkeley in 1960s. His significant contributions towards non-linear circuit theories and introduction of disorderly systems made him decide to design a simple electronic system that would reflect disorder in the higher senses alongside the beauty that comes with it. The Chua circuit is an important milestone in nonlinear dynamics, and it is considered as the cradle of chaos theory since chaos theory started as an academic field.

Early Developments

During the 1970s and 1980s, the Chua circuit and its complex dynamics began to be rigorously scrutinized by researchers. It was found by scientists that a variety of nonlinear behaviors could be generated by this circuit such as oscillations, bifurcations, and strange attractors which were considered to be the reserve of large and more elaborate systems. This research thus led to the recognition of the significance of the Chua circuit in chaotic system comprehension and simulation across sectors including physics, engineering, biology and economics.

Modern Applications

The Chua circuit remains an important scientific tool with many uses because of some of its distinct traits, including its capability for producing disordered signals. This has led to its application in assorted fields such as secure communications, image encryption, and exploring complicated natural systems. Furthermore, it serves as a common benchmark against few postulates of non-linear dynamics and chaos paradigm. Therefore, its continued relevance just goes to show how much Leon Chua's research contributed in our comprehension of nature's intricate operations. Today, some of which are well-known include the Chua oscillator which is a basic circuit element with hysteresis which explains a key non-linear phenomenon known as "Chua circuit" in honor of its inventor Leon Chua

Chaotic Behavior

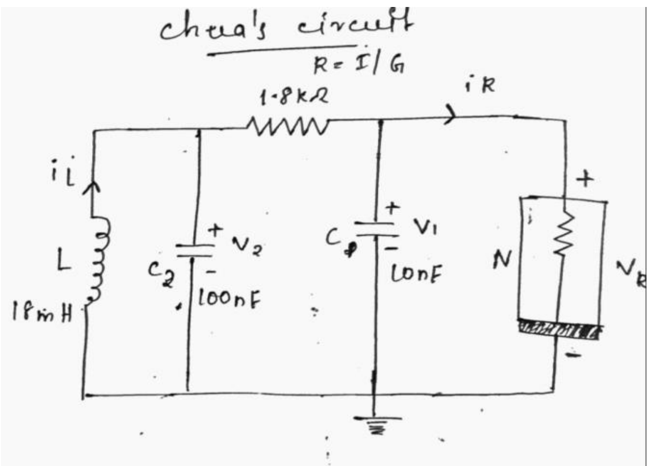
The extraordinary capacity of the Chua circuit to manifest turmoil has attracted attention of many a scientist and engineer. The Chua circuit is fundamentally an unpretentious electric circuit with passive elements such as resistors, capacitors, inductor plus a nonlinear device termed as Chua diode. However much uncomplicated it may seem at a glance, the Chua circuit exhibits a variety of intricate and unpredictable behaviors, for instance strange attractors bifurcations as well as double-scroll attractor which are hallmarks within this system.

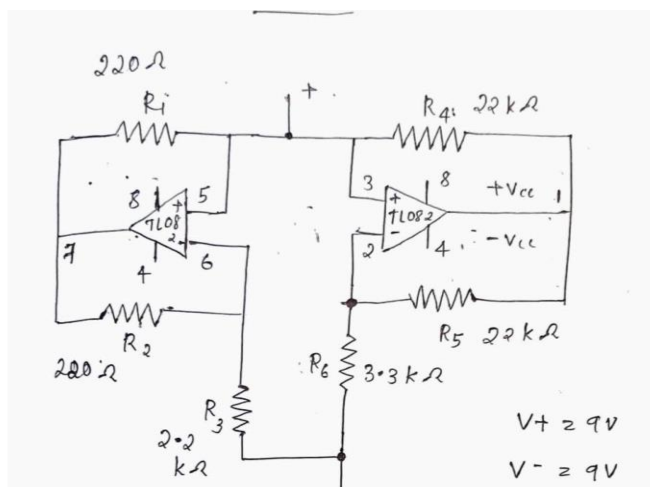
The Chua circuit is known for being a chaotic system which has both linear and nonlinear parts that create this chaos. Chua used a diode with a piecewise linear characteristic to bring in some nonlinearity into it and this resulted into it producing chaotic behavior after being connected with other components of the system. According to the above definition, chaoticity seems to mean that very little modifications done on initial inputs would cause big outputs variations in future time scales. The evolution of chaos is an event that can occur for small alterations made in the system's initial conditions or design parameters with long term effects.By studying the chaotic behavior of the Chua circuit, we have been able to have a better understanding of nonlinear dynamics and chaos theory with associations to different fields like communications, signal processing and even cryptography. However, more research is still going on in this area in order to find out more about its properties and possible uses in technology. It is important to note that non lineariy is the key element in understanding chaos.

Chapter 2

EXPERIMENTAL SETUP

In order to study the complex behavior of the Chua circuit accurately, a well-thought-out experimental plan should be made. A Chua diode, resistors that allow it to function, capacitors, and a power source used for providing right voltage values and electric currents are the main components of a Chua circuit. Normally, it is assembled on electronic or printed unit which supports breadboard, so you can make changes with less effort.





Connecting the circuit to an oscilloscope would enable one observe its chaotic dynamics as it would display the voltage waveforms over time and hence analyze its behavior including strange attractors appearing in the system as well as period-doubling bifurcations while making transition into chaos. Moreover, acquisition systems for recording both voltage and current values might also be employed after which processing can be done by special software.

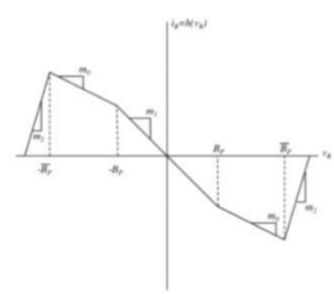
The experimental setup includes provisions for varying the circuit parameters such as resistance, capacitance and the Chua diode characteristics as well as an alternative form of measurement which allows it to vary continuously over its entire range. In this way scientists can investigate various dynamic behavior modes and analyze all basic principles of nonequilibrium systems theory and nonlinear dynamics.

A SIMPLE PARTICLE IMPLEMENTATION OF CHAU'S DIODE

A simple practical implementation of Chua's diode is done by using two operational amplifiers and six resistors. The Chua's diode circuit is then constructed using TLO82 op-amps, two 9 volts batteries and six linear resistors.The value given to the resistances R1 – R6 are 220 ohm, 220 ohm, 2.2KΩ, 22KΩ, 22KΩ and 3.3KΩ respectively. The use of two 9V batteries to power the op- amps gives the voltages V + = 9V and 1 V - = - 9V .

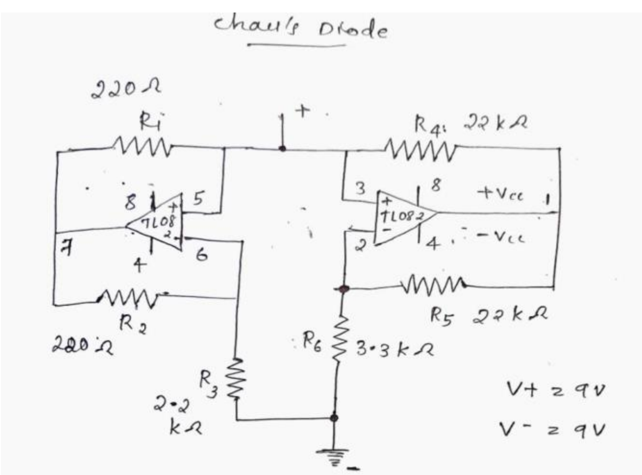
The slopes of the characteristic curve are given by Ga = m1 = - R2/ (R1*R3) - R5/ (R4*R6) = - 0.758mA / V and Gb = m0 = - R2 / (R1*R3) + (1 / R4) = - 0.409mA / V

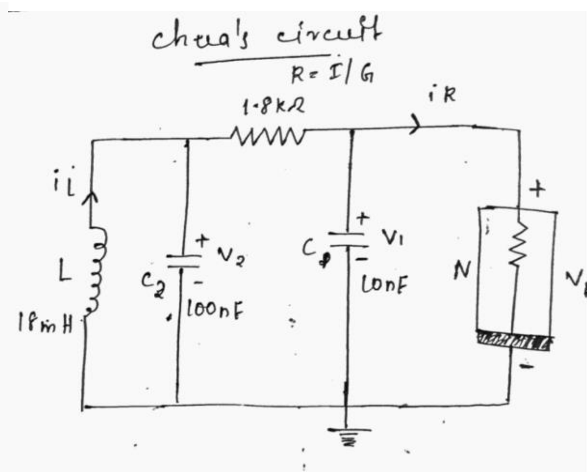
The breakpoints are determined by the saturation voltages E sat of the op-amps. They are calculated as B P =E sat R3 /(R 2 +R 3) approx 7.61 ^ 1 and B P =E sat R 6 /(R 5 +R 6) approx1.08V



The V-I characteristic curve of the op-amp based Chua's diode differs from the desired piecewise-linear characteristics shown in in that as noted above in the latter has only three segments while the former has five segments, the outer two of which have positive slopes Gc = m2 = (1 / R2) = (1/220) * mA / V

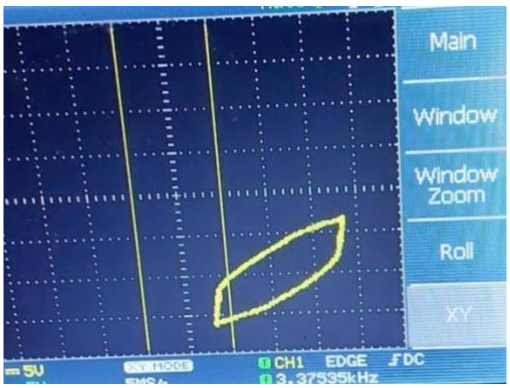
Every physical resistor is eventually passive, This means that, at large enough voltages across a resistor's terminals, the power P(t)(= v(t) * i(t)) in use by it will always be positive and real resistors are said to be eventually passive. As for the v R ^(1)1i R characteristics, they must be only in the first and third quadrants of the vi plane if vary is large enough. For this reason, the UR-IR characteristic of an authentic Chua's diode represents as least two external segments with positive slopes in the first and third quadrants . This study will assume that as long as voltages and currents in any given nonlinear circuit involving Chua's diode are confined within the negative resistive interval of its characteristic curve, those external parts stated above would not influence the dynamical response of such a circuit.

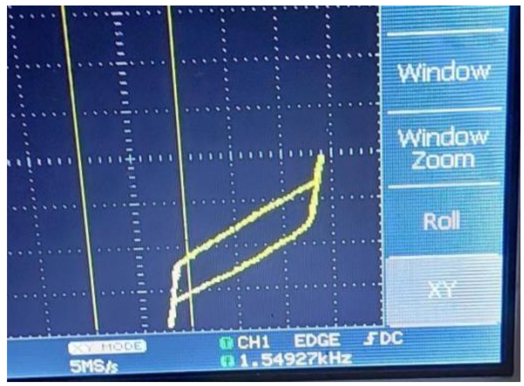


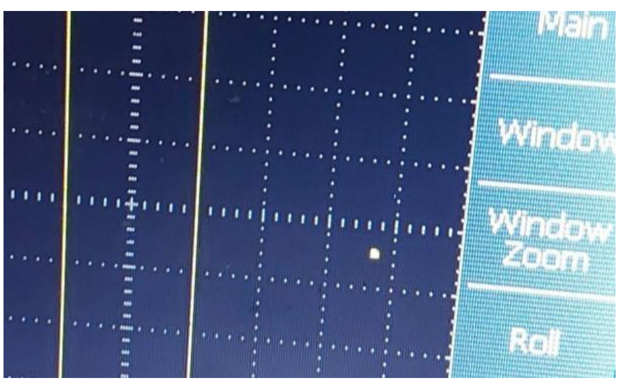


BIFFURCATIONS AND CHAOS

After setting circuit parameters at C1 = 10nF, C2 = 100nF and L = 18mH requirements used by Chua’s team in their experiment. It becomes apparent when lowering the variable resistor R from 2KΩ down to zero levels that a series of bifurcations appears .







In the experimental study, a two-dimensional projection of the attractor is obtained by connecting v1 and v2 to the X and Y channels, respectively, of an oscilloscope. This figure depicts the projection of v1 versus v2 phase portrait. Inserting a small current sensing resistor Rs in series with the inductor L, the current iL can also be measured.

The circuit has a stable equilibrium point for R = 2K*Omega, as indicated. When R is reduced, the system experiences Hopf bifurcation at a critical value, which results in the creation of a stable limit cycle and the instability of the equilibrium point. Figures depict this and explain how the period doubling phenomena leads to pandemonium. One-band chaos is found for R = 1.79K*Omega. The double-scroll attractor, which resembles two paper rolls, is shown in Figure for R = 1.74K*Omega. The trajectory spirals about the equilibrium point, let's say, on the left for a while before moving to the right and spiraling around it multiple times, and so on. A substantial limit cycle, representing the outside segments of the (v-i) characteristic, is observed for R = 1.4KΩ.

An another way is to view the bifurcation sequence is by adjusting C1 or C2 or L. For example, by fixing the values of L, C2 and R at 18mH, 100nF and 1.8KΩ, respectively and varying C1 from 12nF to 6nF, the full range of bifurcations from equilibrium point through Hopf bifurcation, period doubling sequence to spiral Chua attractor and double-scroll Chua attractor can be obtained.

Some of the important features associated with Chua's circuit are the following.

Chua's circuit exhibits a number of different scenarios or routes towards the onset of chaos. These include transition to chaos through period doubling cascade, through breakdown of invariant torus and through intermittency.

Chapter 3

COMPUTER AND CHAOS

Python:

Python is a high-level, general-purpose, and widely used programming language. Web development, Machine Learning, as well as any new technology in software industry are some of the places that this latest python version (Python 3) is being applied.

Python Classes and Objects

Python classes correspond to and individual traits. Objects are simply the individual classes. They give the ways by which data and functions are joined together. Everytime a new class is created a new category of objects is defined. This is what enables the formation of the new instances based on these types. Each object made depends on the state that it should maintain during its usage. A class is defined using a keyword called class, followed by an identifier

Syntax: Class Definition

```
Class ClassName: #
  Statement
```

Syntax: Object Definition

```
Obj = ClassName()

Print(obj.atrr)
```

NumPy

A Python library used for performing operations on tabulated data structures is NumPy. Such things as linear algebra computations, Fourier transformations, and matrix operations are implemented in it. NumPy was developed in 2005 by Travis Oliphant. The uses of this library are open to the public so one can always work with it comfortably. The meaning of the word NumPy is Numerical Python.

Matplotlib is a small graph plotting library in python that serves as a visualization utility.

Matplotlib was created by John D. Hunter.

Matplotlib is open source and we can use it freely.

Pyplot is a Matplotlib module that provides a MATLAB-like interface. Matplotlib is designed to be as usable as MATLAB, with the ability to use Python and the advantage of being free and open source.

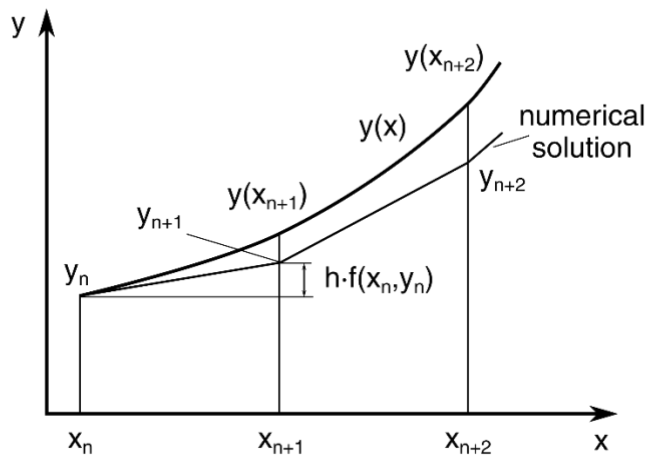
Numerical integration is the approximate computation of an integral using numerical techniques.

EULERS NUMERICAL INTEGRATION FORMULA

Euler's method uses the simple formula,

$y(x+h) = y(x) + hf(x,y)$ to construct the tangent at the point `x` and obtain the value of `y(x+h)`, whose slope is,

$f(x, y)$ or simply, $\frac{dy}{dx}$.



In Euler's method, you can approximate the curve of the solution by the tangent in each interval (that is, by a sequence of short line segments), at steps of `h`. *In general*, if you use small step size, the accuracy of approximation increases.

General Formula

$$y_{i+1} = y_i + hf(x_i, y_i)$$

where,

- y_{i+1} is the next estimated solution value;
- y_i is the current value;
- h is the interval between steps;
- $f(x_i, y_i)$ is the value of the derivative at the current (x_i, y_i) point.

Functional value at any point **b**, given by **y(b)**

$$n = \frac{b - x_0}{h}$$

where,

- **n** = number of steps
- **h** = interval width (size of each step)

Python program

```
import numpy as np import
matplotlib.pyplot as plt


def chua_circuit(x, y, z, t, alpha, beta, m0, m1, m2):
    dxdt = alpha * (y - x - m0*x*(x*x - 1))
dydt = x - y + z     dzdt = -beta * y
return dxdt, dydt, dzdt


# Parameters
alpha = 10.0
beta = 15.6 m0
= -1.143 m1 =
-0.714 m2 = -
0.857


# Initial conditions
x0 = 0.1 y0 = 0.2
z0 = 0.3


# Time span t_span =
np.linspace(0, 100, 10000) dt =
t_span[1] - t_span[0]
```

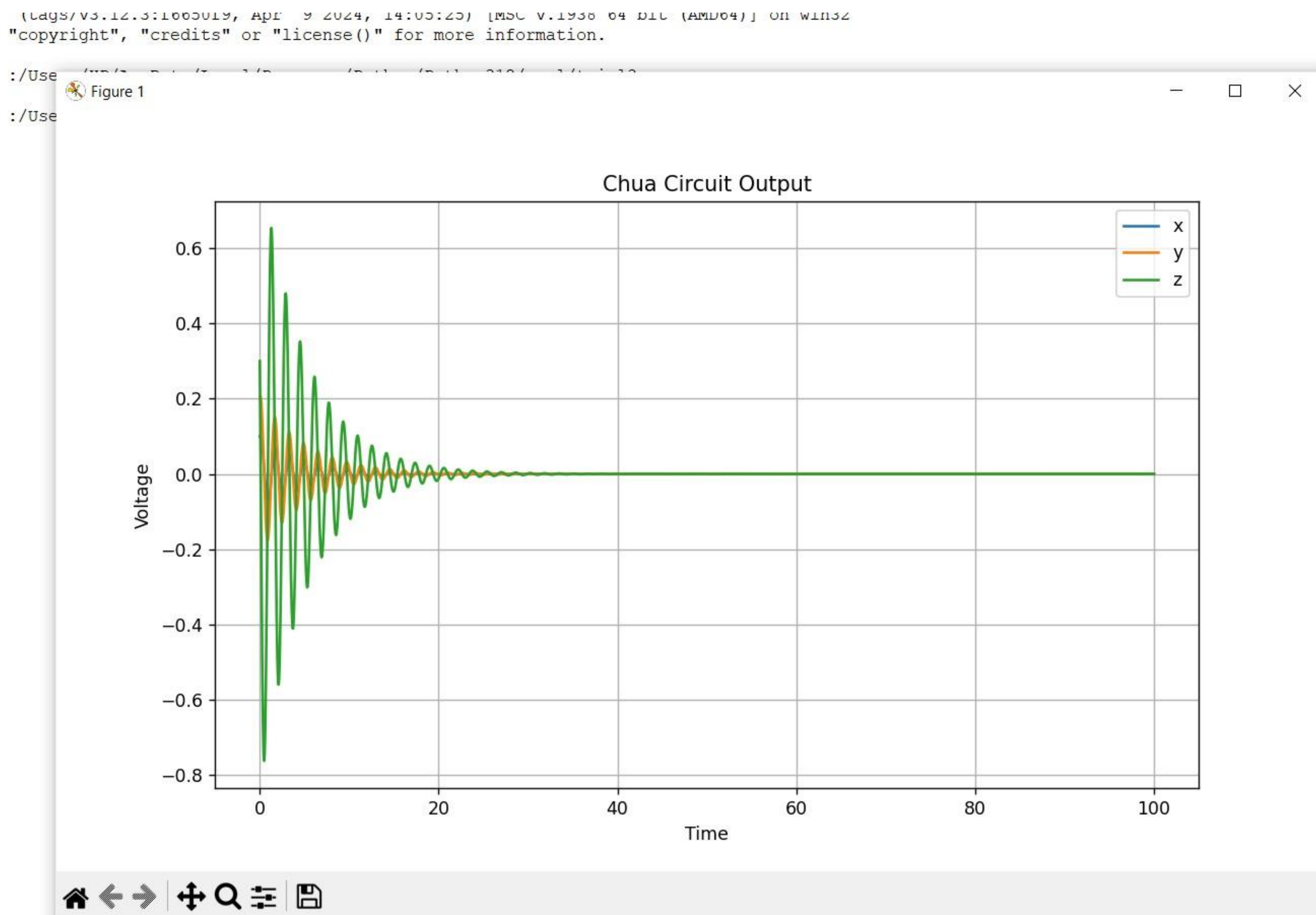
```
# Arrays to store results x_values
= np.zeros_like(t_span) y_values
= np.zeros_like(t_span) z_values
= np.zeros_like(t_span)

# Set initial conditions
x_values[0] = x0
y_values[0] = y0 z_values[0]
= z0

# Numerical integration using Euler's method for
i in range(1, len(t_span)):
    dxdt, dydt, dzdt = chua_circuit(x_values[i-1], y_values[i-1], z_values[i-1], t_span[i-1], alpha,
beta, m0, m1, m2)     x_values[i] = x_values[i-1] + dxdt * dt     y_values[i] = y_values[i-1] + dydt
* dt     z_values[i] = z_values[i-1] + dzdt * dt

# Plot the solution
plt.figure(figsize=(10, 6))
plt.plot(t_span, x_values, label='x')
plt.plot(t_span, y_values, label='y')
plt.plot(t_span, z_values, label='z')
plt.xlabel('Time')
plt.ylabel('Voltage') plt.title('Chua
Circuit Output') plt.legend()
plt.grid(True) plt.show()
```

OUTPUT



This code implements the Chua circuit equations and performs numerical integration using Euler's method to solve the differential equations over a specified time span. Finally, it plots the output voltages of the Chua circuit over time.

Chapter 4

Conclusion and Further research

The Chua circuit has been found to be an exciting and remarkable area of research, indicating how chaotic systems are complex and captivating. The Chua circuit's presence of chaos in a pure system – this nonlinear electronic circuit is a simple illustration Chua's memristor, whose behavior is chaotic. The memristor was a piece of circuitry that when connected to a circuit, would actively alter its resistance. It is the best example that can be used to explain some of the characteristics of electromagnetic inductors. However, information has not been widely spread concerning the theoretical side of this field; unfortunately, there is no definite answer why these principles work in this manner. Moreover, since its discovery in the 1980's by Professor Leon Chua at the University of Berkeley, California; this device has played an astonishing role in electronics, control and various other areas we did not expect them to be applied as such secure communications or be isomorphic computing.

Moving on, the Chua circuit has continued to be inspiring and challenging to all who venture into it whether he/she is a student in electronics or an automotive repair technician; It is full of promises for us expecting greater breakthroughs than ever before which will greatly influence technology as well as our comprehension about natural world. Such discoveries await us providing they are within our reach thereby enabling us to add more colors on this complex fabric called science. "As long as we keep delving deeper into this fascinating realm, we will find new opportunities and become part of a constantly progressing array of knowledge in science.

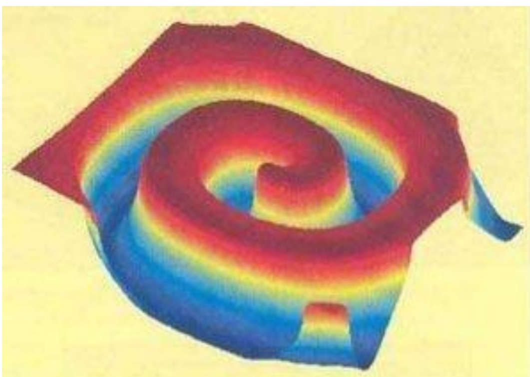
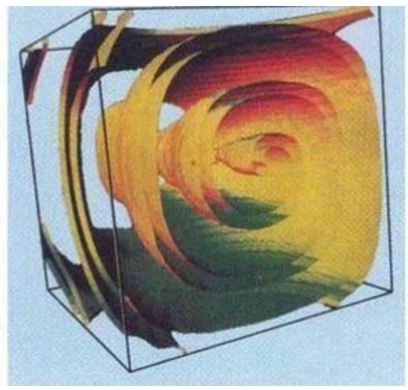
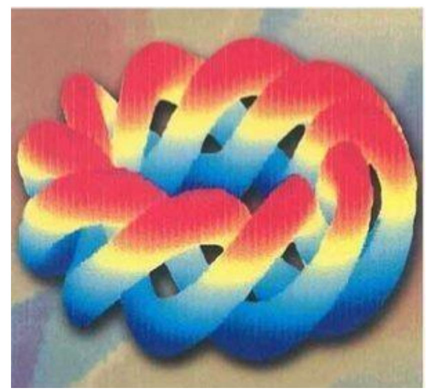
Applications and Uses

The Chua circuit would appear in a variety of industries and has many applications. One area where it excels is chaos theory and nonlinear dynamics, but there are still numerous other examples worth mentioning. To researchers studying complex unpredictable systems, it is important because the chaos shown by this system can serve as a model of this behavior that occurs within them. One of the areas where this circuit is often used is electronics testing where it serves as a source for various testing signals in different ranges or as an equivalent to all settings without any restrictions on possible additions (e.g., very complicated functions). It also allows making different types filters at one time thanks to its capacity generate various waveforms simultaneously.

Further, sensitivity of the initial conditions and parameter changes of the Chua circuit have made it a useful tool for studying dynamic properties of electric circuits and elaboration of novel management rules. In actuality, within communication systems the Chua circuit has been adopted during designing of chaos communication protocols, which use the circuit's chaotic behavior to send and encrypt data in a non-intercept mode. Communication by this means is used in possible cases of cryptography, spread-spectrum communications and secure data transfer .

Also, the field of neuromorphic computing has recently discovered utility for the Chua circuit that acts as a physical realization for some neural network models. Hence, it has become a very useful tool in creation of hardware neural networks and exploration of brain-like computing paradigms. In particular, within the discipline of engineering, Chua circuit finds applications in power electronics systems design and analysis including power converters and power supplies among other types of power electronic systems due to its chaotic behavior whose exploitation can potentially enhance their efficiency and performance while at the same time provide insights into how nonlinear dynamics affect these circuits.

In a plenty of cases—as the chaos theory or electronics, communication systems or neuromorphic computing—the Chua circuit's versatility and capability to reveal a great variety of complex behaviors make it valuable for scientists and technologists.

Chua Circuit's Impact on Modern Society and Future Needs.

The Chua circuit is a simple, yet incredible electronic oscillator which has influenced current societal trends immensely and still plays a central role in determining outcomes.The Chua circuit that is considered as one of the first chaotic circuits has helped in changing the way we consider linear dynamics,thereby leading to a host of extraordinary developments across numerous domains including electronics ,computer science,biology.

n the world of electronics, the Chua oscillator enables the design of communication systems based on chaos that are more secure and robust for data exchange. These systems use the innate unpredictability of the Chua circuit's chaotic behaviour, which makes them more difficult to intercept or jam. The imperative for modem so outline relies on secure, fast transmission as the necessity of these circuits increases.

Moreover, analog computing and neuromorphic engineering applications has found the Chua circuit's ability to display complex, unpredictable behaviors. They are also investigating whether it can mimic some functions carried out by our brains naturally resulting in artificial neural networks as well as cognitive computing systems.

In other words, these new developments have the potential to transform major areas such as image processing, choices, and AI needed to solve today's world problems.

Increasing integration of technology into our daily lives has made the role of the Chua circuit in shaping this landscape more important than ever. For it provides good chaos, better synchronization of systems and makes it an outstanding resource in designing next generation devices and systems. It is clear that Chua circuit shapes future technologies given its influence on developing self-organizing networks and creation of adaptive signal processing algorithms.

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Appendix page

Bifurcation

The bifurcation hypothesis is the numerical analysis of modifications to the subjective or topological structure of a particular family of bends, as the inescapable bends in a vector areas and the arrangements of a family of differential conditions .It happens in a nonlinear differential condition when a little alter in a parameter comes about in a subjective alter within the long-time arrangement.

Strange Attractor

The term 'Strange Attractor' is utilized to portray an attractor (a locale or shape to which focuses are 'pulled' as the result of a certain process) that shows touchy reliance on beginning conditions (that's , focuses which are at first near on the attractor ended up exponentially isolated with time).

Image encryption

Image encryption is the method of stowing away pictures from unauthorized get to employing a mystery key. Picture encryption works by changing the pixel values or visual information of an picture into a mixed or scrambled shape, making it incomprehensible to unauthorized people

Period-doubling bifurcation

In dynamical frameworks hypothesis, a period-doubling bifurcation happens when a slight alter in a system's parameters causes a modern occasional direction to rise from an existing occasional trajectory-the unused one having double the period of the first.