Chaos theory-Design of Chaotic Communication Systems

Dissertation submitted in partial fulfillment of the requirement for the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

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UNDER THE GUIDANCE OF

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DECLARATION BY THE SCHOLAR

We hereby declare that the work reported in the B-Tech thesis entitled **“Chaos theory-Design of Chaotic Communication System”** submitted at **Jaypee University of Information Technology,Waknaghat India,** is an authentic record of our work carried out under the supervision of **Prof. Dr. T. S. Lamba** . We have not submitted this work elsewhere for any other degree or diploma.

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SUPERVISOR'S CERTIFICATE

This is to certify that the work reported in the B-Tech. thesis entitled "**Chaos theory-Design of Chaotic Communication Systems**", submitted by **Adarsh Yadav(121034), Mahak Gupta(121050), Ayush Goyal(121052)** at **Jaypee University of Information Technology, Waknaghat , India,** is a bonafide record of their original work carried out under my supervision. This work has not been submitted elsewhere for any other degree or diploma.

Prof. Dr. T. S. Lamba

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May, 2016

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LIST OF ACRONYMS & ABBREVIATIONS

AWG	Additive White Gaussian
BER	Bit Error Rate
C	Capacitance
CDMA	Code Division Multiple Access
CS	Complete Synchronization
CSK	Chaos Shift Keying
D/A	Digital to Analog and vice-versa
DCSK	Differential Chaos Shift Keying
DPCM	Differential Pulse Code Modulation
DS	Double Sided
DSP	Digital Signal Processing
IF	Intermediate frequency
L	Inductance
LAN	Local Area Network
LPF	Low Pass Filter
NLP	Non-Linear Programming
OOK	On-Off Keying
Op-Amp	Operational Amplifier
PCM	Pulse Code Modulation
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying

R	Resistance
RF	Radio Frequency
SNR	Signal to Noise Ratio

LIST OF SYMBOLS

α ,β ,γ,ϕ	Constants parameters for Chua‟s system
Q	Grey coded data symbol
ω	Angular frequency
λ	Eigenvalue of a system

LIST OF FIGURES

ABSTRACT

Chaotic systems have properties such as ergodicity, sensitivity to initial conditions/parameter mismatches, mixing property, deterministic dynamics, structure complexity, to mention a few, that map nicely with cryptographic requirements such as confusion, diffusion, deterministic pseudo-randomness, algorithm complexity. Furthermore, the possibility of chaotic synchronization, where the master system (transmitter) is driving the slave system (receiver) by its output signal, made it probable for the possible utilization of chaotic systems to implement security in the communication systems. Many methods like chaotic masking, chaotic modulation, inclusion, chaotic shift keying (CSK) had been showed. Different modifications of these methods also exist in the literature to improve the security, but almost all suffer from the same drawback. Therefore, the implementation of chaotic systems in security still remains a challenge. In this work, possibilities on how it might be possible to design a chaotic communication system are explored.

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CHAPTER 1

OVERVIEW OF CHAOS COMMUNICATION

1.1 Objective

Spread-spectrum signals are well known to be resistant to interferers (natural and manmade) and multipath effects, conducive to secure communications by lowering the average spectral density, and effective for use in multiple access systems where users simultaneously re-use the shared communications bandwidth. A notional depiction of the spectral power density of a modulated data signal both before and after spreading is shown in Figure 1.

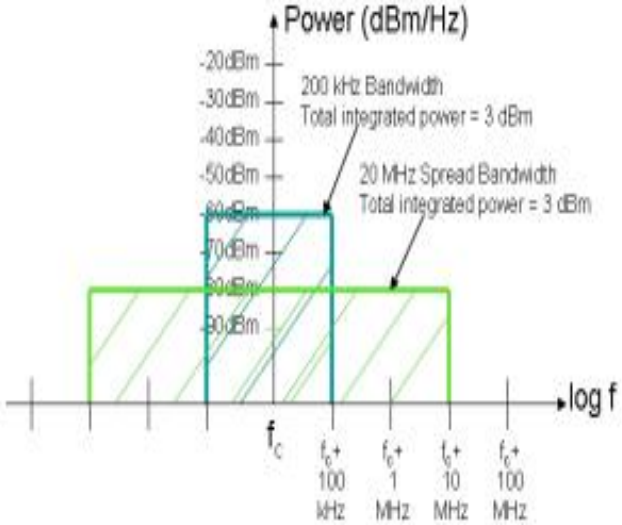


FIGURE 1. Power spectral density effects of signal spreading.

The extension of spread-spectrum signaling techniques to chaotic communications gained active interest in the early 1990s since frequency bandlimited chaotic spreading sequences are known to closely mimic Shannon's ideal noise-like waveform; the chaotic waveform is a near-optimal approximation of a transmission with maximum capacity for carrying information in a Gaussian white noise channel. Compared to other spread communication systems, chaotic waveforms may be viewed as having the potential for higher throughputs (as a result of higher SNR) or a lower power spectral density (increasing spectral re-use) for the same data throughput. Further, the impulsive autocorrelation also gives chaotic waveforms superior multipath and co-interference characteristics as compared to traditional spread-spectrum signals like CDMA.

By contrast with a conventional digital modulation scheme, where the transmitted symbols are mapped to a finite set of periodic waveform segments for transmission, every transmitted symbol in a chaotic modulation scheme produces a different non periodic waveform segment. Because the cross correlations between pieces of periodic segments are lower than between pieces of periodic waveforms, chaotic modulation ought to offer better performance under multipath propagation conditions. Thus, chaotic modulation offers a potentially simple solution for robust wideband communications.

1.2 Chaos Theory

Chaos theory, a branch of the theory of the interesting nonlinear systems, exhibits an interesting nonlinear phenomenon and has been intensively studied in the past four decades. Initially, it was studied by researchers with strong mathematical background rather than circuit-designers or electronic engineers/ scientists. This is mainly due to the fact that circuit design and implementation cannot match up with the mathematical equations needed due to technical and practical problems. With the advance in circuit technology and digital signal processing in the past few decades, the use of chaos phenomena in daily real-life engineering products become possible. Various applications and products were reported, including but not limited to the following; utilizing the advantage of chaotic dynamic behaviour in washing machine technologies, reaction rate control in chemical technologies, treating cardiac arrhythmia and providing a secure communication channel by using a chaotic carrier. Therefore, more and more applications have utilized chaos theory. We are particularly interested in the area of secure communications. Chaotic signals in the time domain are neither periodic nor quasi-periodic and are unpredictable on the long term. This unpredictable phenomenon man- ifests itself as a wideband noise-like power spectrum in the frequency domain. The chaotic dynamic system can be classified into continuous-time and discretetime. A set of differential equations can be used to derive a continuous-time chaotic system as shown below:

$$g(x,t) = \dot{x},\ x(t0) = x0 \qquad (1.1)$$

where g is the set of differential equations to define the dynamical system, x is a vector represents the current state of the system at time t. In our thesis, we will focus on discrete time chaotic systems, the chaotic signal sampled at k th iteration can be given by:

$$x_k = g(x_{k-1}) = g^{(k)}(x_0) \qquad (1.2)$$

where x is the state vector, and g(·) is the iterative function also known as "chaotic map".In addition to it random and non-periodic behaviours, another unique property of chaotic systems is their bifurcation behaviours, where the chaotic system is sensitive for environment changes and highly dependent on its initial conditions. Small difference in the initial condition produces a very different chaotic signal after a short time period. Therefore, one can produce a large number of chaotic signals even with a very simple dynamic deterministic equation.

1.3 Why do we need a chaotic carrier in Communication Systems ?

When a sinusoidal carrier is used, the transmitted power is concentrated in a narrow band, thereby resulting in high power spectral density. This has a number of serious drawbacks:-

- Multipath propagation is always present in many important radio applications such as mobile telephony and wireless LAN. It results in very high attenuation over narrow frequency bands. This means that the SNR may become very low or even a dropout may occur in a narrowband communications system.
- Due to the high transmitted power spectral density, narrowband communications cause high levels of interference with other users. Therefore, they are not suitable for unlicensed radio applications.
- Narrowband signals are sensitive to narrowband interference.
- Because of the high transmitted power spectral density, the probability of interception of narrowband communications is high.
- The reception of messages by an unauthorized receiver is very simple because limited a priori knowledge is required for demodulation.

CHAPTER 2
CONVENTIONS OF PHYSICS

2.1 Description

Spread-spectrum signals are well known to be resistant to interferers (natural and manmade) and multipath effects, conducive to secure communications by lowering the average spectral density, and effective for use in multiple access systems where users simultaneously re-use the shared communications bandwidth. The extension of spread-spectrum signaling techniques to chaotic communications gained active interest in the early 1990ssince frequency bandlimited chaotic spreading sequences are known to closely mimic Shannon's ideal noise-like waveform; the chaotic waveform is a near-optimal approximation of a transmission with maximum capacity for carrying information in a Gaussian white noise channel. Compared to other spread communication systems, chaotic waveforms may be viewed as having the potential for higher throughputs (as a result of higher SNR) or a lower power spectral density (increasing spectral re-use) for the same data throughput. Further, the impulsive autocorrelation also gives chaotic waveforms superior multipath and co-interference characteristics as compared to traditional spread-spectrum signals like CDMA.

2.2 Principles of Chaos Theory

Chaos theory is the field of study of the behavior of dynamical systems that are highly sensitive to initial conditions. Small differences in initial conditions (such as those due to rounding errors in numerical computation) yield widely diverging outcomes for such dynamical systems, rendering long-term prediction impossible in general. This happens even though these systems are deterministic, meaning that their future behavior is fully determined by their initial conditions, with no random elements involved. In other words, the deterministic nature of these systems does not make them predictable.Thisbehavior is known as deterministic chaos, or simply chaos. Lorenz, a meteorologist, was running computerized equations to theoretically model and predict weather conditions. Having run a particular sequence, he decided to replicate it. Lorenz reentered the number from his printout, taken half-way through the sequence, and left it to run. What he found upon his return was, contrary to his expectations, these results were radically different from his first outcomes. Lorenz had, in fact, entered not precisely the same number, .506127, but the rounded figure of .506. According to all scientific expectations at that time, the resulting sequence should have differed only very slightly from the original trial, because measurement to three decimal places was considered to be fairly precise. Because the two figures were considered to be almost the same, the results should have likewise been similar.

2.2.1 The Butterfly Effect

The phrase refers to the idea that a butterfly's wings might create tiny changes in the atmosphere that may ultimately alter the path of a tornado or delay, accelerate or even prevent the occurrence of a tornado in another location. The butterfly does not power or directly create the tornado, but the term is intended to imply that the flap of the butterfly's wings can cause the tornado: in the sense that the flap of the wings is a part of the initial conditions; one set of conditions leads to a tornado while the other set of conditions doesn't. The flapping wing represents a small change in the initial condition of the system, which cascades to large-scale alterations of events (compare: domino effect). Had the butterfly not flapped its wings, the trajectory of the system might have been vastly different—but it's also equally possible that the set of conditions without the butterfly flapping its wings is the set that leads to a tornado. Thus the Butterfly Effect is a phrase that encapsulates the more technical notion of sensitive dependence on initial conditions in chaos theory. The idea is that small variations in the initial conditions of a dynamical system produce large variations in the long term behavior of the system. Sensitive dependence is also found in non-dynamical systems: for example, a ball placed at the crest of a hill might roll into any of several valleys depending on slight differences in initial position.

2.2.2 Unpredictability

Unpredictability of a system does not mean the absence of order as the name of chaos theory implies; it means: a confusing interaction between order and randomness. The natural shape of chaos takes the form of strange attractors: “strange” meaning the complex geometry of unpredictability; “attractor” meaning the system’s long-term mode of behavior, the point to which a system returns after a disturbance, like homeostasis or equilibrium. The order found

2.2.3 Order\disorder

Chaos is not simply disorder. Chaos explores the transitions between order and disorder, which often occur in surprising ways.

2.2.4 Mixing

Turbulence ensures that two adjacent points in a complex system will eventually end up in very different positions after some time has elapsed. Examples: Two neighboring water molecules may end up in different parts of the ocean or even in different oceans. A group of helium balloons that launch together will eventually land in drastically different places. Mixing is thorough because turbulence occurs at all scales. It is also nonlinear: fluids cannot be unmixed.

2.3 Feedback

Systems often become chaotic when there is feedback present.

2.4 fractals

A fractal is a never-ending pattern. Fractals are infinitely complex patterns that are self-similar across different scales. They are created by repeating a simple process over and over in an ongoing feedback loop. Driven by recursion, fractals are images of dynamic systems – the pictures of Chaos. Geometrically, they exist in between our familiar dimensions. Fractal patterns are extremely familiar, since nature is full of fractals.

2.5 Non-Linear Systems

A non-linear system is a system in which the output is not directly proportional to the input. Nonlinear systems may appear chaotic, unpredictable or counterintuitive, contrasting with the much simpler linear systems.

2.5.1 Dynamic Systems

The dynamics is a rule that transforms one point in the phase space (that is, a world state), representing the state of the system "now", into another point (= world state), representing the state of the system one time unit "later".. In mathematical language, the dynamics is a **function** mapping world states into world states. The state of the system at any point depends on its prior states and is the starting point for future states. Behavior emerges in the moment, but the effects of each behavioral decision accumulate over longer time scales, as each change sets the stage for future changes. Development occurs within a system, which is the result of (a) components, (b) patterns of relationships among components, (c) processes that arise from the interaction of components, and (d) outcome . Any change in a system impacts other components of the system. In this way, it is possible to say what state the system will be in at a particular time in the future.

2.5.2 Linear Dynamic systems

Linear dynamical systems are dynamical systems whose evaluation functions are linear. While dynamical systems in general do not have closed-form solutions, linear dynamical systems can be solved exactly, and they have a rich set of mathematical properties. Linear systems can also be used to understand the qualitative behavior of general dynamical systems, by calculating the equilibrium points of the system and approximating it as a linear system around each such point.

2.6 Chaos Vs Complexity

We can now consider further the similarities and differences between chaotic systems and complex systems. Each shares common features, but the two concepts are very different. Chaosis the generation of complicated, aperiodic, seemingly random behaviour from the iteration of a simple rule. This complicatedness is not complex in the sense of complex systems science, but rather it is chaotic in a very precise mathematical sense. Complexity is the generation of rich, collective dynamical behaviour from simple interactionsbetween large numbers of subunits. Chaotic systems are not necessarily complex, and complex systems are not necessarily .The interactions between the subunits of a complex system determine(or generate) properties in the unit system that cannot be reduced to the subunits (and that cannot be readily deduced from the subunits and their interactions). Such properties are known as emergent properties. In this way it is possible to have an upward (or generative) hierarchy of such levels, in which one level of organisation determines the level above it, and that level then determines the features of the level above it. Emergent properties may also be universal or multiply realisable in the sense that there are many diverse ways in which the same emergent property can be generated. For example, temperature is multiply realisable: many configurations of the same substance can generate the same temperature, and many different types of substance can generate the same temperature. The properties of a complex system are multiply realisable since they satisfy universal laws—that is, they have universal properties that are independent of the microscopic details of the system. Emergent properties are neither identical with nor reducible to the lower-level properties of the subunits because there are many ways for emergent properties to be produced.A necessary condition, owing to nonlinearity, of both chaos and complexity is sensitivity to initial conditions. This means that two states that are very close together initially and that operate under the same simple rules will nevertheless follow very different trajectories over time. This sensitivity makes it difficult to predict the evolution of a system, as this requires the initial state of the system to be described with perfect accuracy. There will always be some error in how this is performed and it is this error that gets exponentially worse over time. It is possible to see how this might pose problems for replication of initial conditions in various types of trial and intervention.

There are several less well-understood, but nonetheless important properties that are characteristic features of complex systems. Complex systems often exhibit self-organisation, which happens when systems spontaneously order themselves (generally in an optimal or more stable way) without “external” tuning of a control parameter (see below). This feature is not found in chaotic systems and is often called anti-chaos.Such systems also tend to be out of equilibrium, which means that the system never settles in to a steady state of behaviour. This is related to the concept of openness: a system is open if it is not or cannot be screened off from its environment. In closedsystems, outside influences (exogenous variables) can be ignored. For open systems, this is not the case. Most real-world systems are open, thus this presents problems both for modelling and experimenting on such systems, because the effect of exogenous influences must be taken into account. Such influences can be magnified over time by sensitivity to initial conditions.

Another important feature of a complex system is the idea of feedback, in which the output of some process within the system is "recycled" and becomes a new input for the system. Feedback can be positive or negative: negative feedback works by reversing the direction of change of some variable; positive feedback increases the rate of change of the variable in a certain direction. In complex systems, feedback occurs between levels of organisation, micro and macro, so that the micro-level interactions between the subunits generate some pattern in the macro-level that then "back-reacts" onto the subunits, causing them to generate a new pattern, which back-reacts again and so on. This kind of "global to local" positive feedback is called coevolution, a term originating in evolutionary biology to describe the way organisms create their environment and are in turn moulded by that environment.

If a system is stable under small changes in its variables, so that it does not change radically when interventions occur then it is said to be robust. Generally, complex systems increase in robustness over time because of their ability to organise themselves relative to their environment. However, it is possible for single events to alter a complex system in a way that persists for a long time (this is called path-dependence). For a complex system, "history matters.

The key differences between chaotic systems and complex ones lie, therefore, in the number of interacting parts and the effect that this has on the properties and behaviour of the system as a whole. . Complex systems are coherent units in a way that chaotic systems are not, involving instead interactions between units. This simple difference concerning units and subunits can be brought out using concepts from the theory of critical phenomena, which is central to complexity science.

CHAPTER 3
BACKGROUND OF CHAOTIC COMMUNICATION

3.1 Description

A solution that reflects the unpredictable nature of our world is the "Chaos Theory". It provides the required kind of system behavior (non-linear, dynamic, unpredictable . Overview of Chaos Communications and etc), thus it has been widely studied by mathematicians and scientists alike. A chaotic system is a deterministic system that exhibits non-linear systems behavior with certain distinguished features . There are a lot of definitions for the chaotic system, which is in simple term "A system that becomes aperiodic (non-linear) if its parameter, internal variable, external signals, control variable, or even initial value is chosen in a specific way", we call this unpredictable behavior of a deterministic system as chaos theory or chaos system. So we use some chaotic map to generate chaotic signals.

3.2 Chaotic Maps

Generations of chaotic maps came from many different directions. It can be a complex or simple control system, a mathematical equation such as a differential equation, or a simple circuit modelling like Chua circuit. Such a mathematical model of chaos theory often involves repeated iteration of simple mathematical formulas.

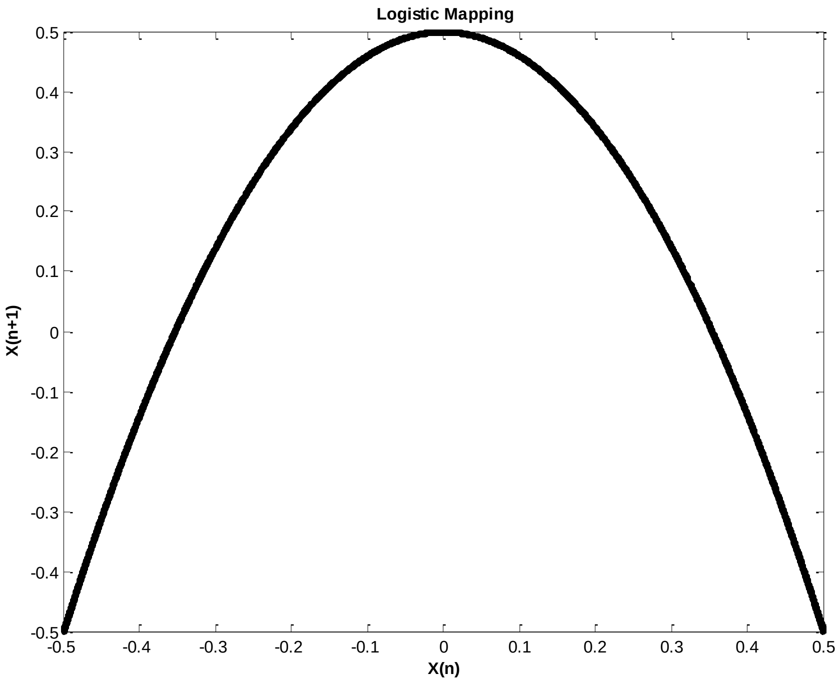
Some chaotic mapping are described as below:

3.2.1 Logistic Map

The logistic map is a polynomial mapping (equivalently, recurrence relation) of degree 2, often cited as an archetypal example of how complex, chaotic behaviour can arise from very simple non-linear dynamical equations. Mathematically, the logistic map is written as:

$$(1) \qquad x_{n+1} = r x_n (1 - x_n)$$

The plot of Logistic mapping as shown below:-



3.2.2 Bernoulli's map / Folded - Baker's map

In dynamical systems theory, the **bernoulli's map** is a chaotic map from the unit square into itself. It is named after a kneading operation thatbakers apply to dough: the dough is cut in half, and the two halves are stacked on one another, and compressed.

The baker's map can be understood as the bilateral shift operator of a bi-infinite two-state lattice model. The baker's map is topologically conjugate to the horseshoe map. In physics, a chain of coupled baker's maps can be used to model deterministic diffusion.

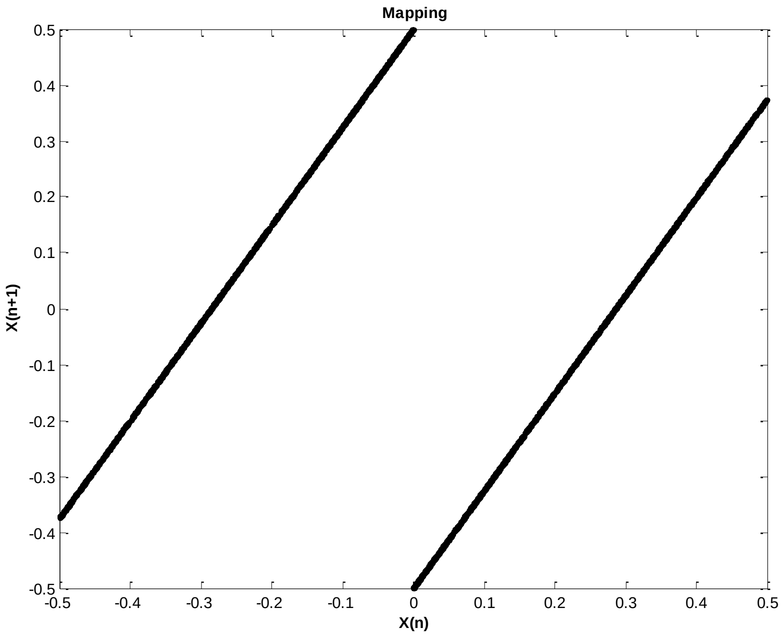
As with many deterministic dynamical systems, the baker's map is studied by its action on the space of functions defined on the unit square. The baker's map defines an operator on the space of functions, known as the transfer operator of the map. The baker's map is an exactly solvable model of deterministic chaos, in that the eigenfunctions and eigenvalues of the transfer operator can be explicitly determined.

The folded baker's map acts on the unit square as

$$S_{\text{baker-folded}}(x, y) = \begin{cases} (2x, y/2) & \text{for } 0 \le x < \frac{1}{2} \\ (2-2x, 1-y/2) & \text{for } \frac{1}{2} \le x < 1. \end{cases}$$

The Bernoulli map can be understood as the map that progressively lops digits off the dyadic expansion of *x*. Unlike the tent map, the baker's map is invertible.

The plot of Logistic mapping as shown below:-



3.2.3 Tent Map

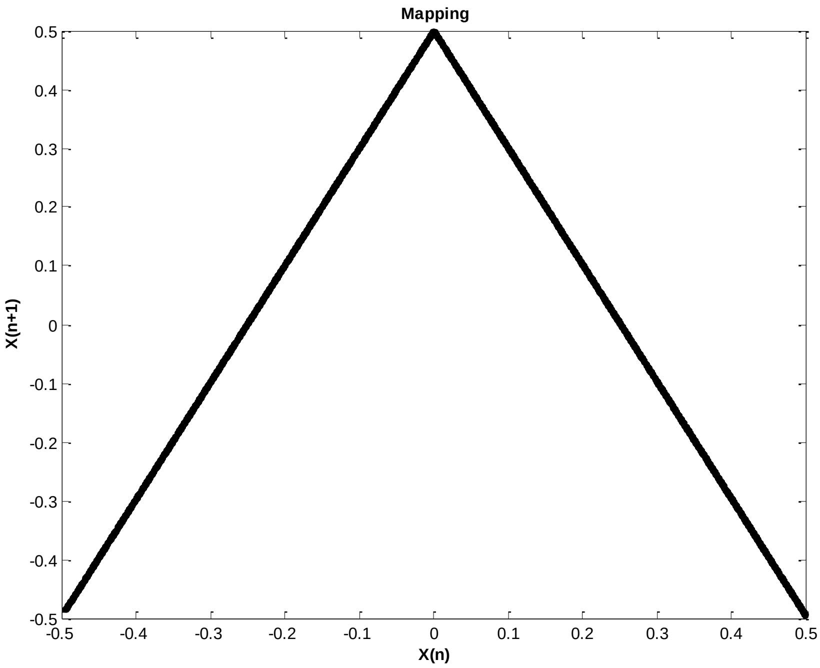
In mathematics, the **tent map** with parameter μ is the real-valued function f_μ defined by

$$f_\mu := \mu \min\{x,\, 1-x\},$$

the name being due to the tent-like shape of the graph of f_μ. For the values of the parameter μ within 0 and 2, f_μ maps the unit interval [0, 1] into itself, thus defining a discrete-time dynamical system on it (equivalently, a recurrence relation). In particular, iterating a point x_0 in [0, 1] gives rise to a sequence x_n :

$$x_{n+1} = f_\mu(x_n) = \begin{cases} \mu x_n & \text{for } \; x_n < \frac{1}{2} \\ \\ \mu(1-x_n) & \text{for } \; \frac{1}{2} \le x_n \end{cases}$$

where μ is a positive real constant. Choosing for instance the parameter μ=2, the effect of the function f_{μ} may be viewed as the result of the operation of folding the unit interval in two, then stretching the resulting interval [0,1/2] to get again the interval [0,1]. Iterating the procedure, any point x_0 of the interval assumes new subsequent positions as described above, generating a sequence x_n in [0,1]. The plot of tent map is shown as



3.2.4 **Quadratic Map**

A quadratic map is a quadratic recurrence equation of the form

$$x_{n+1} = a_2 x_n^2 + a_1 x_n + a_0.$$

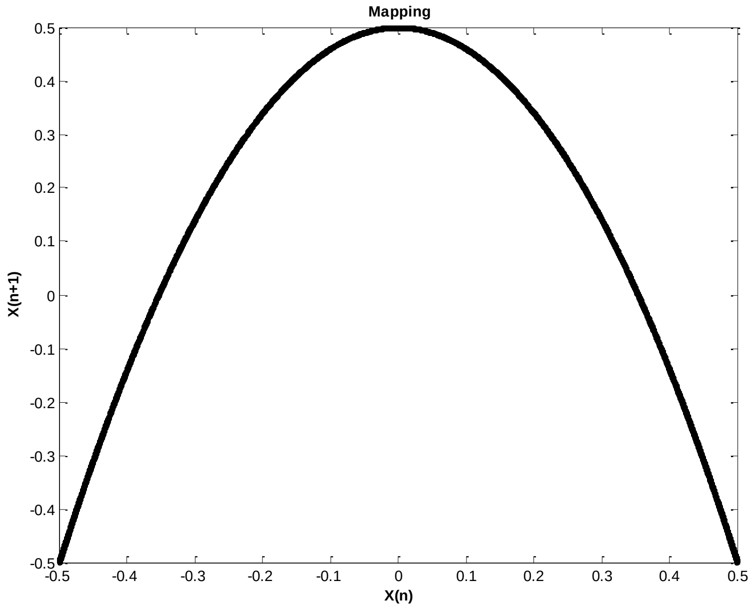
While some quadratic maps are solvable in closed form (for example, the three solvable cases of the logistic map), most are not. A simple example of a quadratic map with a closed-form solution is

$$x_n = x_{n-1}^2$$

When it is used as an evolution function of the discrete nonlinear dynamical system and it is known as the quadratic mapping. The quadratic mapping plot is shown as

$$z_{n+1} = f_c(z_n)$$

$$f_c : z \to z^2 + c.$$



3.3 Chaos Shift Keying (CSK)

In binary chaos shift keying modulation, chaotic signals carrying different bit energies are used to transmit the binary information . An information signal is encoded by transmitting one chaotic signal x1(t) or x0(t) at a time. For example, if the information signal binary bit "1" occurrs at time t, the chaos signal x1(t) is to be sent, and for information bit "0", the chaos signal x0(t) is to be sent. The two chaotic signals can come from two different chaos systems or the same system with different parameters. The transmitted signal is given by

$$s(t) = \begin{cases} x_1(t) & \text{, symbol "1" is transmitted} \\ x_0(t) & \text{, symbol "0" is transmitted} \end{cases}$$

We concentrate on antipodal CSK modulation technique. Both of the chaotic signals are inverted copies of each other (x0(t) = −x1(t)). The transmitted signal can then be expressed as

$$s(t) = \begin{cases} x_0(t) & \text{, symbol "1" is transmitted} \\ -x_0(t) & \text{, symbol "0" is transmitted} \end{cases}$$

The demodulation can be coherent and non-coherent. The coherent demodulation can be seen as a correlator, where the receiver does contain copies of the chaos generator system information (x1(t) and x0(t)). Depending on the transmitted signal, one of these copies will synchronized with the received. Overview of Chaos Communications signal and the the other will be de-synchronized at the receiver. Hence, the match/mismatch will tell about the transmitted information bits.

3.4 Differential Chaos Shift Keying (DCSK)

The differential chaos shift keying was introduced in [55] and shows to outperform CSK schemes when the channel condition is so poor that it is impossible to achieve chaotic synchronization. This modulation scheme is similar to that of the differential phase shift keying (DPSK) except that the transmitted signal is a chaotic - generated signal. In DCSK modulation, each transmitted symbol duration is divided into two identical time slots. The first time slot serves as a reference while the second slot carries the information. If bit "1" is to be sent, the chaotic reference signal (in first slot) is repeated in the second slot; if bit "0" is to be sent, an inverted copy of the reference signal (in first slot) will be sent. Hence, the transmitted signal for information bit "1" is given by

$$s(t) = \begin{cases} x_0(t) & \text{for}(l-1)T_b \le t < (l-1/2)T_b \\ x_0(t - T_b/2) & \text{for}(l-1/2)T_b \le t < lT_b \end{cases}$$

if the information bits is "0",

$$s(t) = \begin{cases} x_0(t) & \text{for}(l-1)T_b \leq t < (l-1/2)T_b \\ -x_0(t - T_b/2) & \text{for}(l-1/2)T_b \leq t < lT_b \end{cases}$$

At the receiver the two received signals are correlated and the decision is made by a zero threshold comparator. The biggest drawbacks of DCSK are the Eb is double and the symbol rate is halved. However, it also offers several advantages over CSK in high noise channel environments. DCSK does not require synchronization and is not sensitive to channel distortion as some other coherent methods are; this is so since both the reference signal and the information signal pass through the same channel.

3.5 CSK Theoretical Background

The performance of the CSK system in an AWGN environment can be derived following the method used . For a correlator type of receiver, the correlator output for the lth bit yl is given by

$$y_l = \sum_{k=2\beta(1-l)+1}^{2\beta l} r_k g_k$$

wherErk = sk + ηk is the received signal in an AWGN environment during the k th chip period, ηk being additive Gaussian white noise. Now we have:

$$y_l = \alpha_l \sum_{k=2\beta(1-l)+1}^{2\beta l} g_k^2 + \sum_{k=2\beta(1-l)+1}^{2\beta l} \eta_k g_k$$

The first term is the required signal and second term is noise. According to the Central Limit Theorem, if we consider a sum of a large number of random variables in the system, we can assume that the system to follow a normal distribution. Hence the BER for the CSK can be formulated as follows:

$$\begin{aligned}\mathrm{BER}_{CSK} &= \mathrm{Prob}(\alpha_l = 1) \times \mathrm{Prob}(y_l \leq 0 \mid \alpha_l = 1) \\ &+ \mathrm{Prob}(\alpha_l = -1) \times \mathrm{Prob}(y_l > 1 \mid \alpha_l = -1) \\ &= \frac{1}{4}\left[\mathrm{erfc}\left(\frac{\mathrm{E}[y_l \mid (\alpha_l = +1)]}{\sqrt{2\mathrm{var}[y_l \mid (\alpha_l = +1)]}}\right)\right. \\ &\quad \left. + \mathrm{erfc}\left(\frac{-\mathrm{E}[y_l \mid (\alpha_l = -1)]}{\sqrt{2\mathrm{var}[y_l \mid (\alpha_l = -1)]}}\right)\right]\end{aligned}$$

whereerfc(.) is the complementary error function defined as

$$\mathrm{erfc}(\psi) \equiv \frac{2}{\sqrt{\pi}} \int_{\psi}^{\infty} e^{-\lambda^2} d\lambda.$$

3.6 Chaos CDMA

Conventional CDMA spread spectrum has an explosive impact on our daily personal communications. The CDMA system can be seen in our daily communication devices, especially in third generation (3G) mobile systems, where it aims to provide us with the ability to use voice and data services between the mobile terminals. In order to provide these services, we must provide an efficient radio link that provides high-frequency, low-power and multiple access communication, where every user appears as white noise signal to all other users using the same link. To do so, we can either spread each symbol using a pseudorandom sequence to increase the bandwidth of the transmitted signal, or represent each symbol by a piece of"noiselike" waveform. Hence, the chaos noise generator can be used.

The properties of chaotic signals suitable for CDMA have been widely studied and shown to provide advantage over the conventional methods of generating the spreading code sequence. The natural property of chaotic signals that produces a bifurcation behavior makes it possible to generate "noise-like" signals, theoretically and practically. In the conventional noise generator, the pseudo random generator or specially designed CDMA code sequence is produced by visiting each state of the system once in a deterministic manner. With only a finite number of states to visit, this sequence is necessarily to be periodic. On the other hand, the chaotic system in theory has an infinite number of analog states and therefore produces an output sequence which never repeat itself. Hence, exploiting the random, noise-like and aperiodic properties of chaos theory makes it possible to use chaos in generating a new class of CDMA code sequences.

The fundamental difference between a traditional direct sequence spread-spectrum communication system and a coherent chaotic sequence spread spectrum communication system is the absence of apparent periodicity in the chaotic waveform. The chaotic sequence is effectively a quadrature pair of independent Gaussian random variables as opposed to a (possibly pulseshaped) string of constant-amplitude square-wave pulses. In general, any correlation, definable characteristic, or waveform feature can be viewed as lowering the entropy of the signal, moving away from Shannon's ideal noise-like waveform. As an example, consider the time-domain spreading sequences shown in Figure , where a four times oversampled chaotic sequence (dark) is plotted next to a comparable four times oversampled pulse-shaped DS spreading sequence (light).

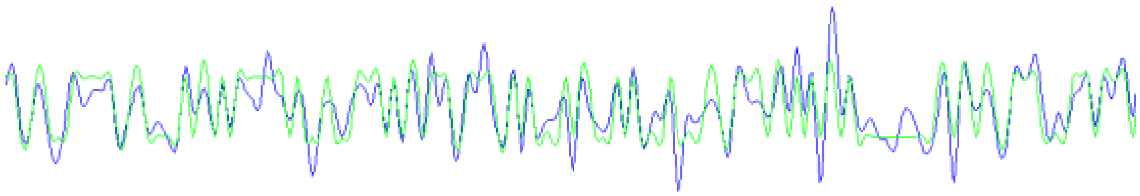
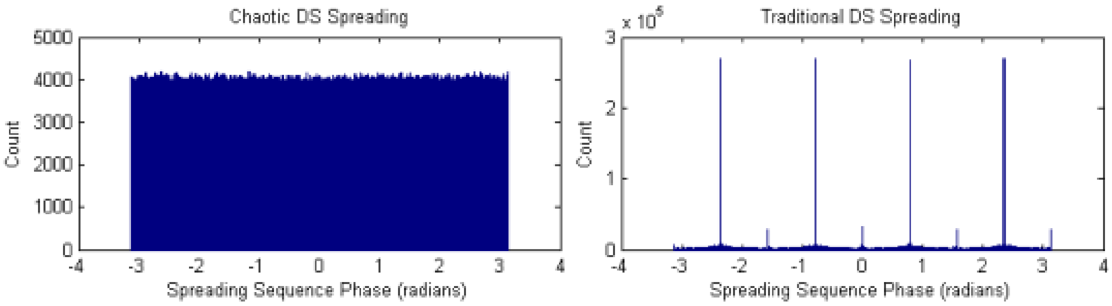


Figure: comparision of traditional & DS spread spectrum

The combination of a quadrature pair of the chaotic spreading sequences will result in a uniformly distributed phase for the chaotic spreading sequence as opposed to a non-random cyclo-stationary distribution for the DS spreading sequence.



Transitioning from a time-domain view to the frequency domain or a statistical analysis yields other verifications that the chaotic sequence modulated waveforms approximate the maximal entropy noise-like signals that Shannon described as optimal for transmission through AWGN channels. Chaotic waveforms have ideal flat spectral power densities and Gaussian distributed amplitudes on each of their in-phase and quadrature components, compared to peak-ish uniform amplitude distributions at four distinct phases for the traditional DS spreading waveform. These characteristics will be discussed and quantified thoroughly in this dissertation by the use of time domain, frequency domain, and statistical measures.

CHAPTER-4
ELECTRONIC CIRCUITS & CHAOS

4.1 Introduction

Chua's circuit (also known as a Chua circuit) is a simple electronic circuit that exhibits classic chaos theory behavior. This means roughly that it is a "nonperiodic oscillator"; it produces an oscillating waveform that, unlike an ordinaryelectronic oscillator, never "repeats". It was invented in 1983 by Leon O. Chua, who was a visitor at Waseda University inJapan at that time. The ease of construction of the circuit has made it a ubiquitous real-world example of a chaotic system, leading some to declare it "a paradigm for chaos.

4.2 Chua Equations

By rescaling the circuit variables vC1, vC2, and iL, we obtain the following dimensionless Chua Equations involving 3 dimensionless state variables x, y, z, and only 2 dimensionless parameters α and β :

Chua Equations

$$\dot{x}\dot{y}\dot{z}===\alpha(y-\phi(x))x-y+z-\beta y$$

where α and β are real numbers, and $\phi(x)$ is a scalar function of the single variable x. The Chua Equations are simpler than the Lorenz Equations in the sense that it contains only one scalar nonlinearity, whereas the Lorenz Equations contains 3 nonlinear terms, each consisting of a product of two variables . In the original version studied in-depth in, $\phi(x)$ is defined as a piecewise-linear function

$$\phi(x)=\Delta x+g(x)=m1x+12(m0-m1)[|x+1|-|x-1|]$$

where m_0 and m_1 denote the slope of the inner and outer segments of the piecewise-linear function respectively. Although simpler smooth scalar functions, such as polynomials, could be chosen for $\phi(x)$ without affecting the qualitative behaviors of the Chua Equations, a continuous (but not differentiable) piecewise-linear function was chosen strategically from the outset in order to devise a rigorous proof showing the experimentally and numerically derived double scroll attractor is indeed chaotic. Unlike the Lorenz attractor , it was possible to prove the double scroll attractor from the Chua Circuit is chaotic by virtue of the fact that certain Poincare return maps associated with the attractor can be derived explicitly in analytical form via compositions of eigen vectors within each linear region of the 3-dimensional state space.

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4.3 Circuit Diagram and Realization

The circuit diagram contains 5 circuit elements. The first four elements on the left are standard off-the-shelf linear passive electrical components; namely, inductance $L > 0$, resistance $R > 0$, and two capacitances $C_1 > 0$ and $C_2 > 0$. They are called passive elements because they do not need a power supply (*e.g.*, battery). Interconnection of passive elements always leads to trivial dynamics, with all element voltages and currents tending to zero.

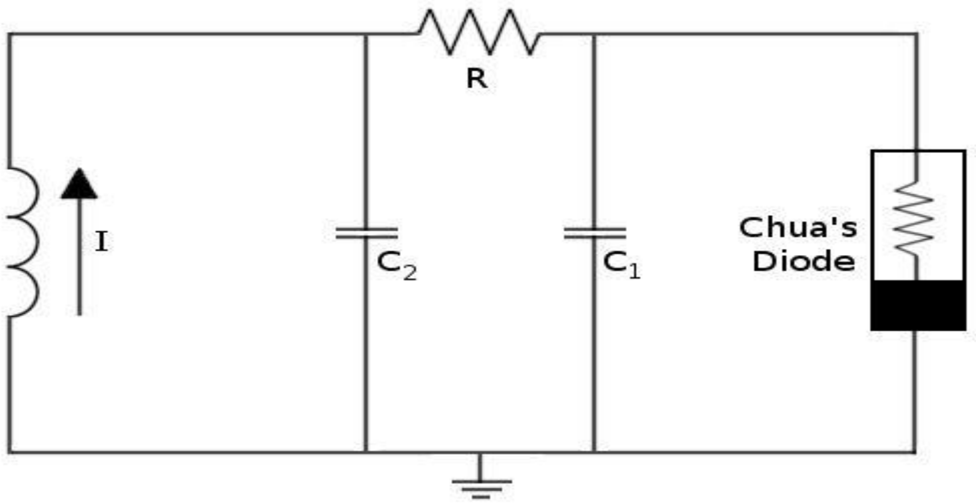


Fig: A Simple Chua's circuit

4.3.1 Local Activity is Necessary for Chaos

The simplest circuit that could give rise to oscillatory or chaotic waveforms must include at least one locally active , nonlinear element, powered by a battery, such as the Chua diode , characterized by a current vs. voltage nonlinear function $iR=g(vR)$, whose slope must be negative somewhere on the curve. Such an element is called a locally active resistor. Although the function $g(\cdot)$ may assume many shapes,the original Chua circuit specifies the 3-segment piecewise-linear odd-symmetric characteristic, where m_0 denotes the slope of the middle segment and m_1 denotes the slope of the two outer segments ; namely,

$$g(vR)= m1vR+m1-m0m0vRm1vR+m0-m1, if vR\leq -1, if -1\leq vR\leq 1, if 1\leq Vr$$

where the coordinate of the two symmetric breakpoints are normalized, without loss of generality, to $vR = \pm 1$.

4.3.2 The Chua Diode is Locally Active

The Chua diode is not an off-the-shelf component. However, there are many ways to synthesize such an element using off-the-shelf components and a power supply, such as batteries. The circuit for realizing the Chua diode need not concern us since the

dynamical behavior of the Chua Circuit depends only on the 4 parameter values L, R, C_1, C_2 and the nonlinear characteristic function $g(\cdot)$.
Any locally active device requires a power supply for the same reason a mobile phone cannot function without batteries .

Figure 2: Realization of Chua diode using two Op Amps and six linear resistors.

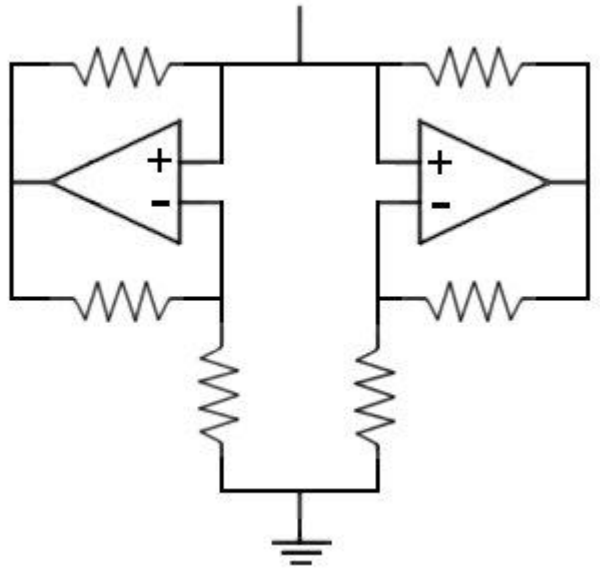


Figure 3: Realization of Chua diode using standard diode.

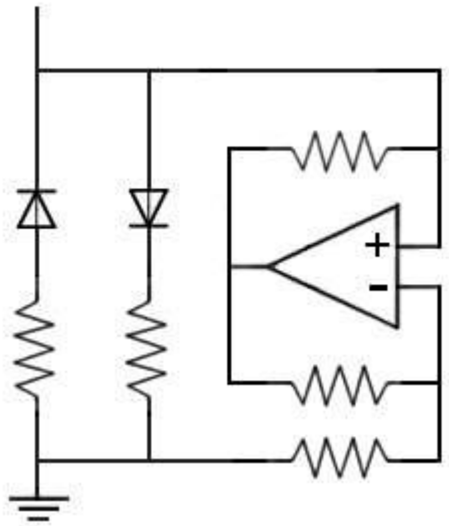
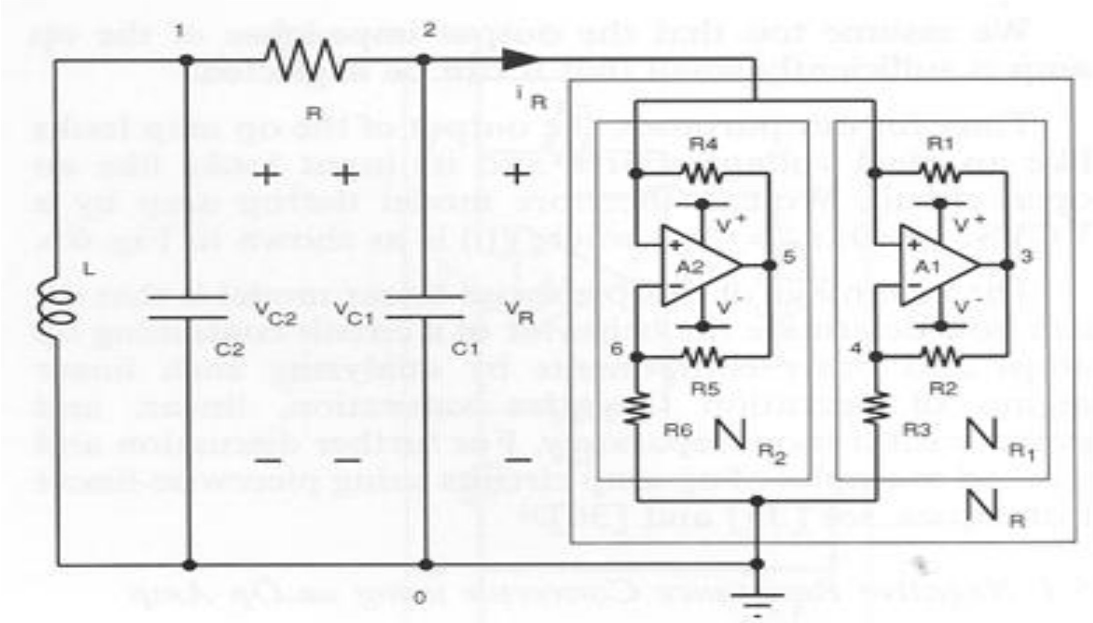


Figure below shows the complete Chua Circuit, including the circuit schematic diagram (enclosed inside the box N_R) for realizing the Chua diode, using 2 standard Operational Amplifiers (Op Amps) and 6 linear resistors.

The two vertical terminals emanating from each Op Amp (labeled $V+$ and $V-$, respectively) in Figure 4 must be connected to the plus and minus terminals of a 9 volt battery, respectively.

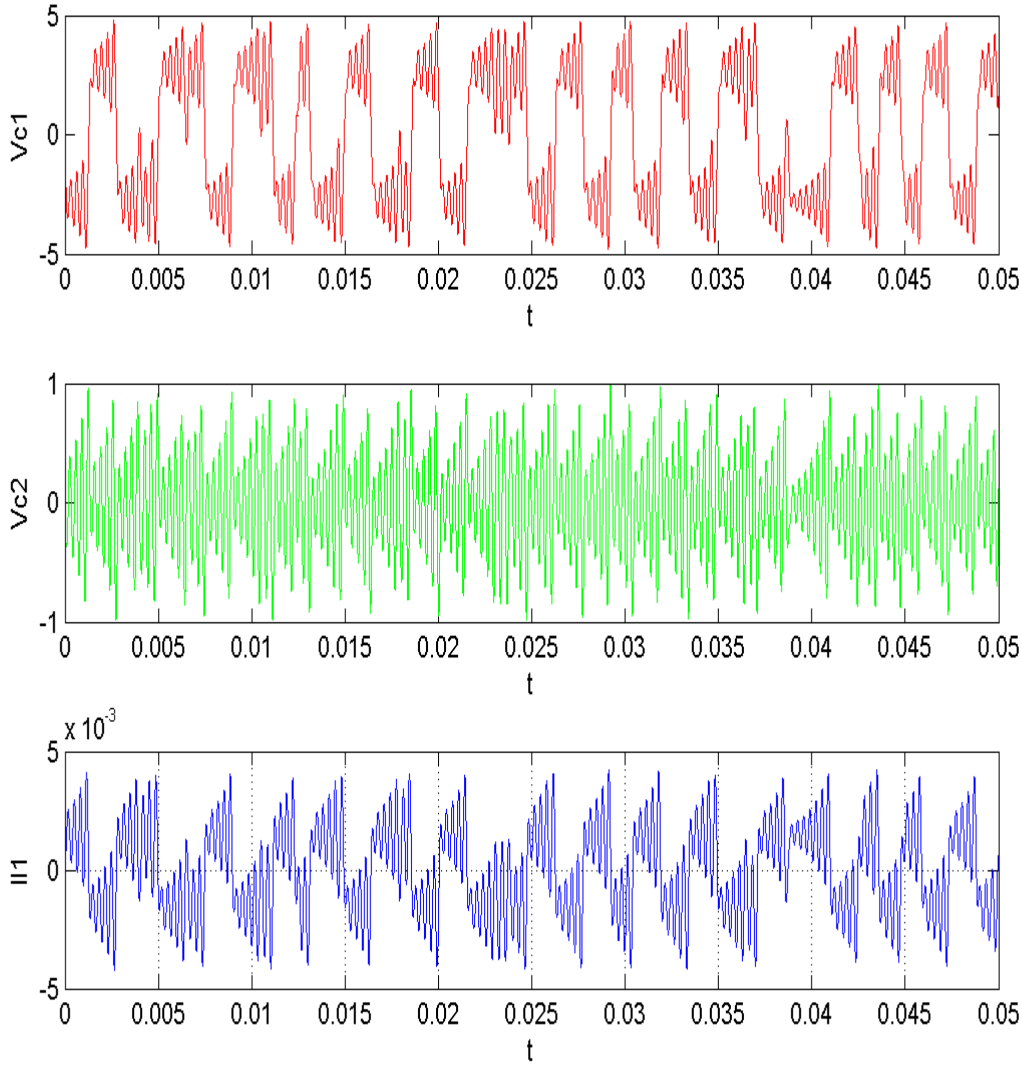


4.4 Oscilloscope Displays of Chaos

Using the Chua Circuit shown in Figure , the voltage waveforms $vC1(t)$ and $vC2(t)$ across capacitors C_1 and C_2, and the current waveform iL(t) through the inductor L in Figure 1, were observed using an oscilloscope and displayed in Figure..

The Lissajous figures associated with 3 permutated pairs of waveforms are displayed on the right column Figure namely, in the $vC1-iL$ plane in Figure the $vC1-vC2$ plane in Figure 5(e), and the $vC2-iL$ plane Figure 5(f). They are 2-dimensional projections of the chaotic attractor, called the double scroll, traced out by the 3 waveforms from the left column in the 3-dimensional $vC1-vC2-iL$ space.

It is important to point out that the Chua Circuit is not an analog computer. Rather it is a physical system where the voltage, current, and power associated with each of the 5 circuit elements in Figure can be measured and observed on an oscilloscope, and where the power flow among the elements makes physical sense. In an analog computer(usually using Op Amps interconnected with other electronic components to mimic some prescribed set of differential equations), the measured voltages have no physical meanings because the corresponding currents and powers can not be identified, let alone measured, from the analog computer.



The three waveforms displayed in (a), (b), and (c) (left column) correspond to to *vC*1(*t*), *vC*2(*t*) and *iL*(*t*), respectively.

4.5 Matlab Code for chua's circuit

Chua diode

```
function out = RealChua(t,in)

x = in(1);
y = in(2);
z = in(3);

C1  = 10*10^(-9);   %10nF
C2  = 100*10^(-9);  %100nF
```

```
R = 1800;          %1.8k Ohms
G = 1/R;

R1 = 220;
R2 = 220;
R3 = 2200;
R4 = 22000;
R5 = 22000;
R6 = 3300;

Esat = 9;
E1 = R3/(R2+R3)*Esat;
E2 = R6/(R5+R6)*Esat;

m12 = -1/R6;
m02 = 1/R4;
m01 = 1/R1;
m11 = -1/R3;

m1 = m12+m11;

if(E1>E2)
m0 = m11 + m02;
else
m0 = m12 + m01;
end

mm1 = m01 + m02;
Emax = max([E1 E2]);
Emin = min([E1 E2]);


if abs(x) <Emin
   g = x*m1;
elseif abs(x) <Emax
    g = x*m0;
if x > 0
    g = g + Emin*(m1-m0);
else
    g = g + Emin*(m0-m1);
end

elseif abs(x) >= Emax
    g = x*mm1;
if x > 0
        g = g + Emax*(m0-mm1) + Emin*(m1-m0);
else
        g = g + Emax*(mm1-m0) +  Emin*(m0-m1);
end
```

```
end
R7  = 100;
R8  = 1000;
R9  = 1000;
R10 = 1800;
C   = 100*10^(-9); %100nF
L = R7*R9*C*R10/R8; %18mH

xdot = (1/C1)*(G*(y-x)-g);
ydot = (1/C2)*(G*(x-y)+z);
zdot  = -(1/L)*y;

out = [xdotydotzdot]';
```

Chua Circuit-

```
[t,y] = ode45(@RealChua,[0 0.05],[-0.5 -0.2 0]);
subplot(3,1,1)
plot(t,y(:,1),'r')
xlabel('t');
ylabel('Vc1');
subplot(3,1,2)
plot(t,y(:,2),'g')
xlabel('t');
ylabel('Vc2');
subplot(3,1,3)
plot(t,y(:,3),'b')
xlabel('t');
ylabel('Il1');
grid
```

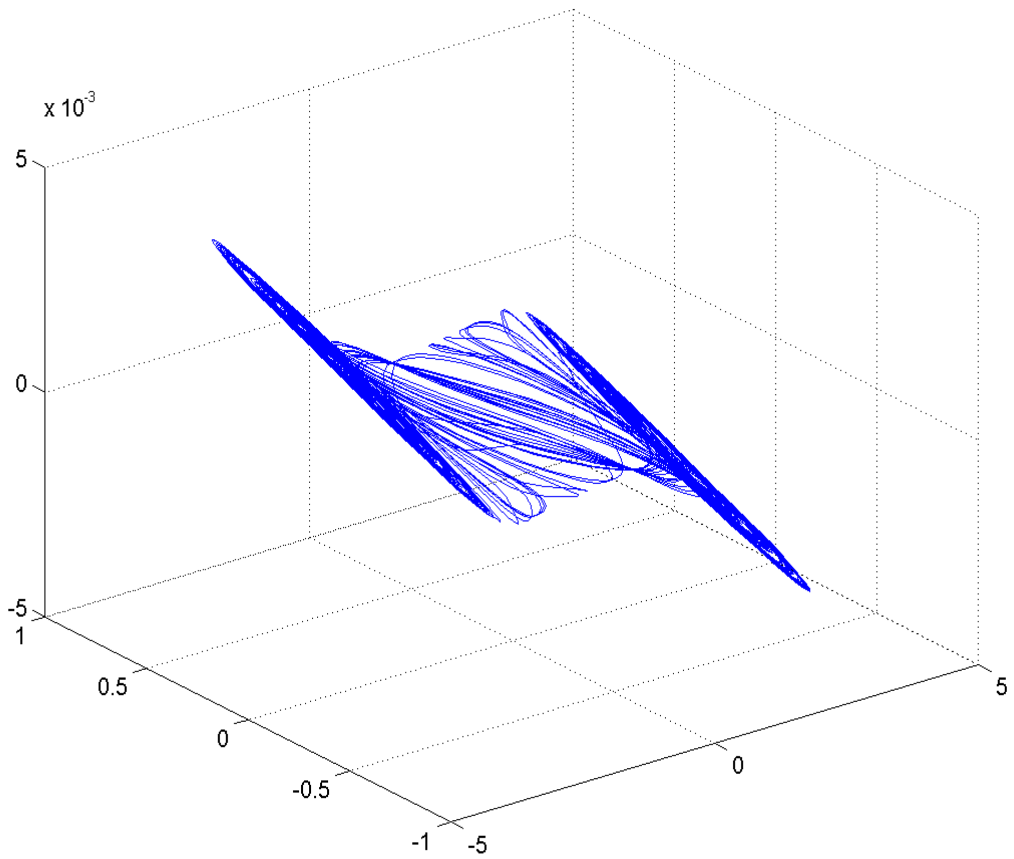
4.6 Control of Chua's-circuit

To control the system it is important to know where errors occur. The errors that occur can come from the tolerances of the resistor, conductor and operational amplifiers. And because this system is chaotic, the small tolerances can result in large differences. If all resistors and conductors have their maximum tolerance offset there will be a worst-case scenario. For a resistor a tolerance of one percent is acceptable. For the conductor that is ten percent. The maximum output voltage of the operational amplifier varies between twelve and fourteen volt .

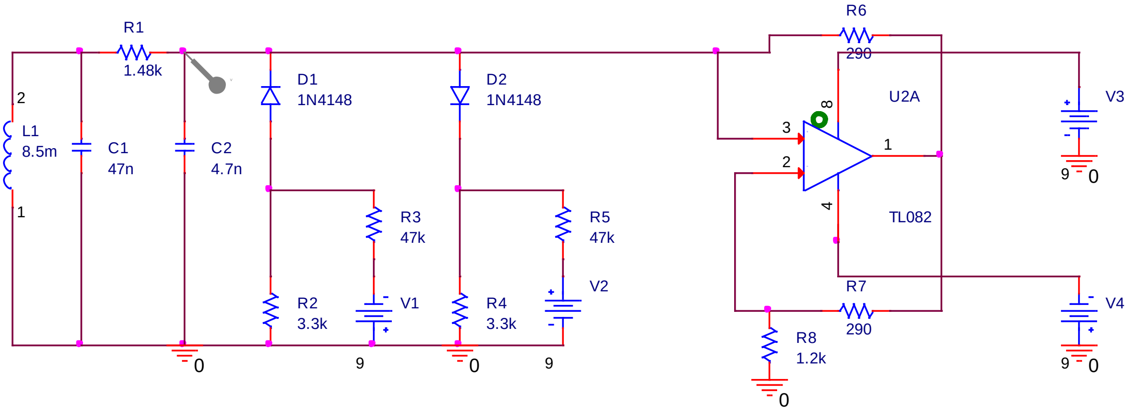
4.7 Double-scroll attractor

sometimes known as Chua's attractor is a strange attractor observed from a physical electronic chaotic circuit (generally, Chua's circuit) with a single nonlinear resistor (see Chua's Diode). The double-scroll system is often described by a system of three nonlinear ordinary differential equations and a 3-segment piecewise-linear equation (see Chua's equations). This makes the system easily simulated numerically and easily manifested physically due to Chua's circuits' simple design.

Using a Chua's circuit, this shape is viewed on an oscilloscope using the X, Y, and Z output signals of the circuit. This chaotic attractor is known as the double scroll because of its shape in three-dimensional space, which is similar to two saturn-like rings connected by swirling lines.



4.8 Implementation using PSpice



4.9 Circuit Simulation & Results

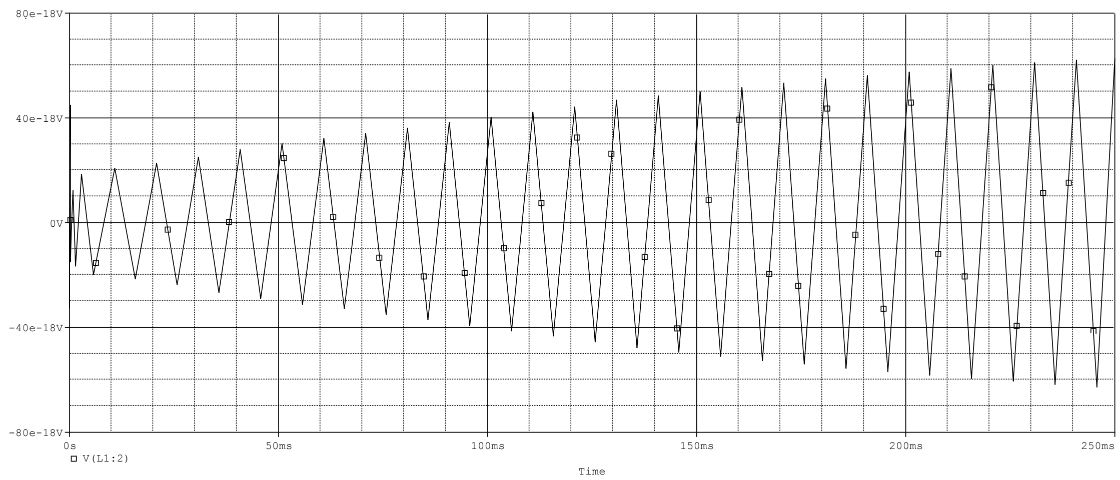


Fig: Voltage across capacitor C1

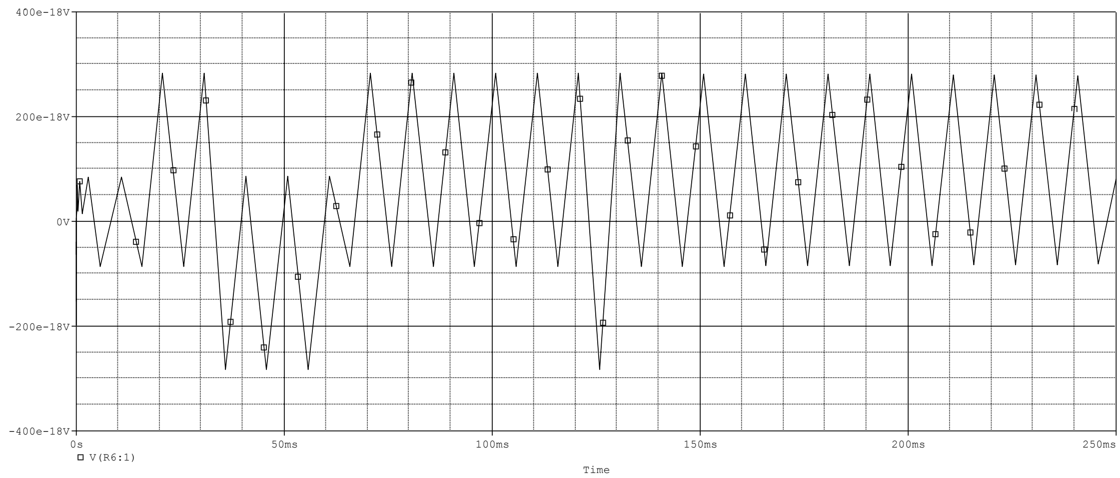


Fig: Voltage across capacitor C2

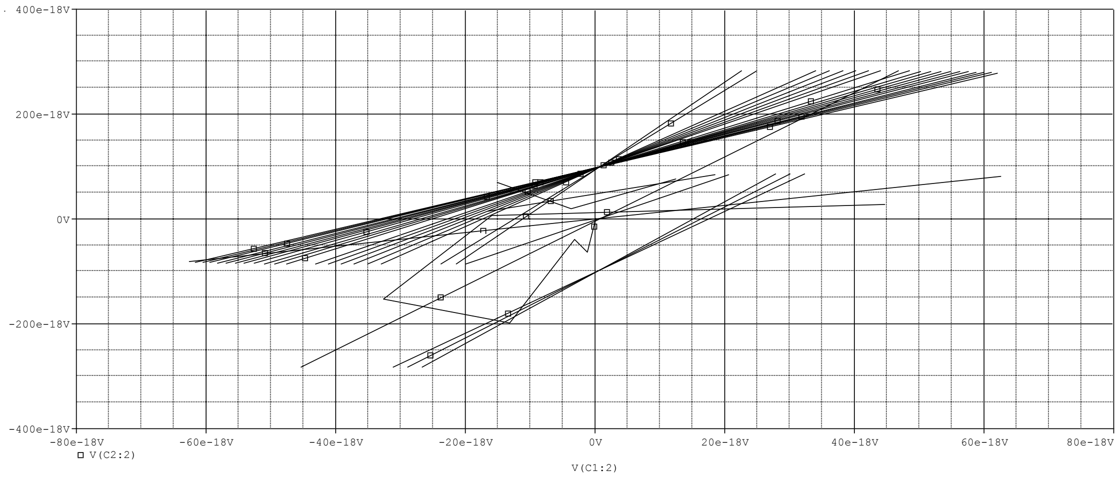


Fig:Double Scroll Attractor

4.10 Conclusion

There are a lot of conclusions that can be drawn. It is shown that the output signals of v1 and v2 are different when the adjustable resistor is changed one thousand to two thousand ohm and turned round. There is also a difference in the quantity of stable points. When the resistor is changed from two thousand ohm downwards to one thousand ohm there are more stable points.

Chua's circuit is build from different components. Each component has a certain tolerance. But because it is a chaotic circuit, a little difference in the component, can lead to large differences in the nl-ltc.nmhg voltages.

CHAPTER 5

PROJECT DESCRIPTION

5.1 Practical Aspects

Given a practically infinite sequence that approximates additive white Gaussian noise, the goal becomes harnessing this sequence to create a robust maximum entropy chaotic communication system. The statistical properties discussed in the previous chapter must be retained throughout the chaotic circuit initialization and control, data modulation, subsequent filtering, data conversion, and RF upconversion. Most of the previous work in chaotic communication systems focused on employing the chaotic circuit to modulate user data; common methods include phase shift keying, pulse amplitude modulation, carrier frequency hopping, and/or combinations thereof. Preferably, the modulation scheme will not change the statistical characteristics of the signal, yet offer compatability with higher capacity modulation schemes like QAM variants.

Finally, considerations must be given to application of the chaotic communication system, quantified as frequency re-use characteristics, signal entropy and features, size/weight/power (SWaP), along with any unintended consequences of design choices. Summarizing the ideal characteristics of a practical communication system based on a digital chaotic circuit:

- A **practically infinite chaotic sequence** provides the fundamental code permitting the intended user to receive the information. To approach both Shannon's information capacity ideal noise-like waveform, the transmitted waveform should be indistinguishable from maximal entropy AWGN.
- A **robust chaotic sequence synchronization** method is absolutely required for a chaotic waveform since the sequence has a naturally impulsive autocorrelation. This synchronization scheme must also contend with the traditional non idealities like frequency offsets, timing offsets, clock jitter, and gain control.
- An **efficient data modulation** scheme is required to encode and decode the user information in a coherent fashion that fully utilizes the transmission bandwidth.

- **Successful integration of the RF transmit** chain into the baseband processing is required to mitigate the effects of D/A conversion, frequency upconversion from IF to RF, and transmission through the antenna.
- An **optimized receiver architecture** that adapts to signal dynamics and can efficiently convert the spread wavefom to meaningful information. The basic structures for frequency, phase, and time tracking are derived as generalizations of direct sequence spread spectrum receiver technology.

5.2 Chaotic Communications Transmitter

The fundamental understanding of the data modulation process, predicted effects and performance in different transmission channel conditions, and a limited amount of implementation criteria have been established. The chaotic phase shift keying modulation shows the greatest practical applicability to coherent communication system design, with theoretical Eb/N0 performance approaching that of traditional PSK modulations and consists of a relatively simple modulation mechanism.

5.3 Data Source and Symbol Formatting

The data source and symbol formatting blocks provide a QPSK formatted symbol that can be directly phase modulated (complex multiplication) by the chaotic spreading sequence. At the conclusion of the preamble, a pair of disambiguity symbols are transmitted to assist the receiver in receiving a selectable frequency inverted/noninverted signal. The symbols are formatted using a traditional Gray code as shown in Figure, ensuring that most symbol errors result in the error of only one bit.

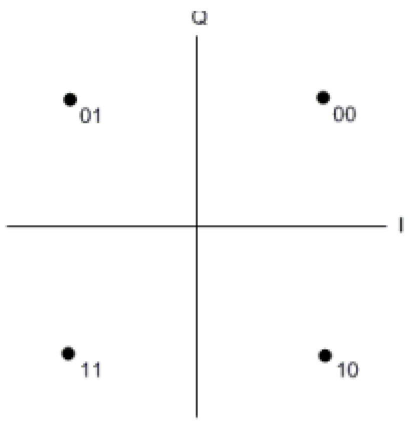


Figure: Grey coded data symbol

5.4 Chaotic Sequence Generation

The chaotic sequence generator, which includes the Box-Muller transformation NLP, provides a steady stream of quadrature standard normal random variables for phase modulation of the QPSK-formatted data symbols. . To set the state of the chaotic sequence generator, it is assumed that both the transmitter and the receiver share an initial condition (key) that is loaded during initialization of the sequence generator.

5.5 Chaotic Communications Receiver

The traditionally difficult task in implementing a coherent chaotic communication system has been satisfactorily synchronizing the chaotic circuits at the transmitter and receiver. In general, coherent chaotic receivers can recreate exact duplicates of the chaotic sample functions used at the transmitter to modulate data; non-coherent receivers lack the ability to recreate or maintain a lock on all possible chaotic state evolutions experienced at the transmitter.

5.6 Chaotic Receiver Timing Control

The impulsive autocorrelation of the chaotic waveform necessitates a highly robust timing control methodology that ensures the relative delay between the received chaotic waveform and the internally generated chaotic sequence is less than one spreading chip duration. Moreover, the ability to time synchronize the received and internally generated chaotic signals within approximately 0.1 spreading chip durations (10 ns) is prefered to reduce receiver implementation loss and susceptibility to time tracking loop errors.

5.7 Simulation Result

Our simulation result presents chaotic hop communication system wherein hoping is not in terms of frequency but in terms of different chaotic sequences.

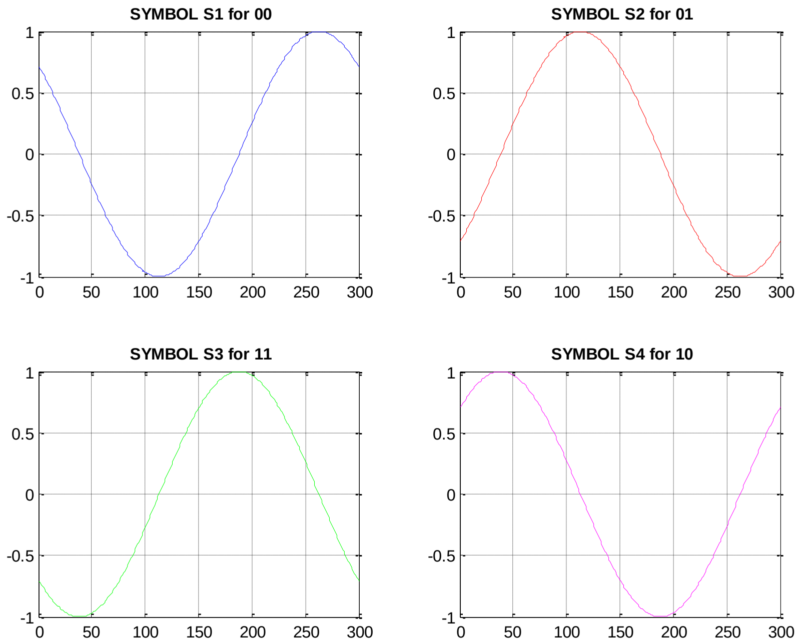


Figure: Carriers for QPSK technique

Figure: Input sequence and Carrier signal

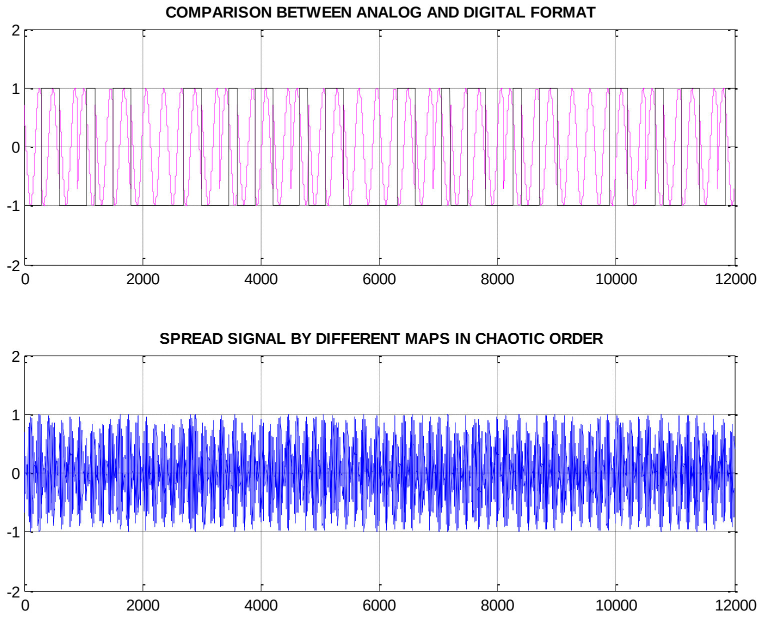


Figure: Modulated Signal and Chaotic generator

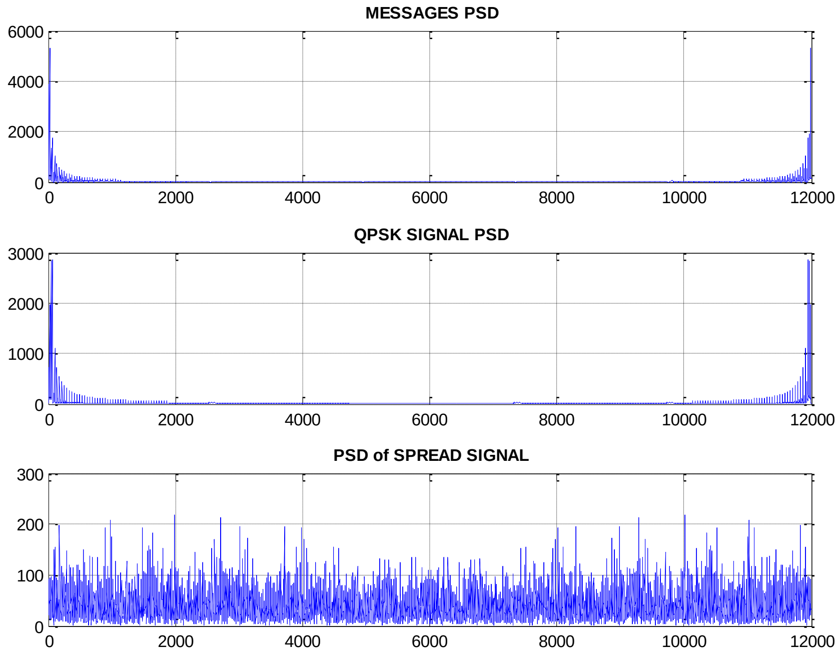


Figure: PSD of different Signals

BER Comparison

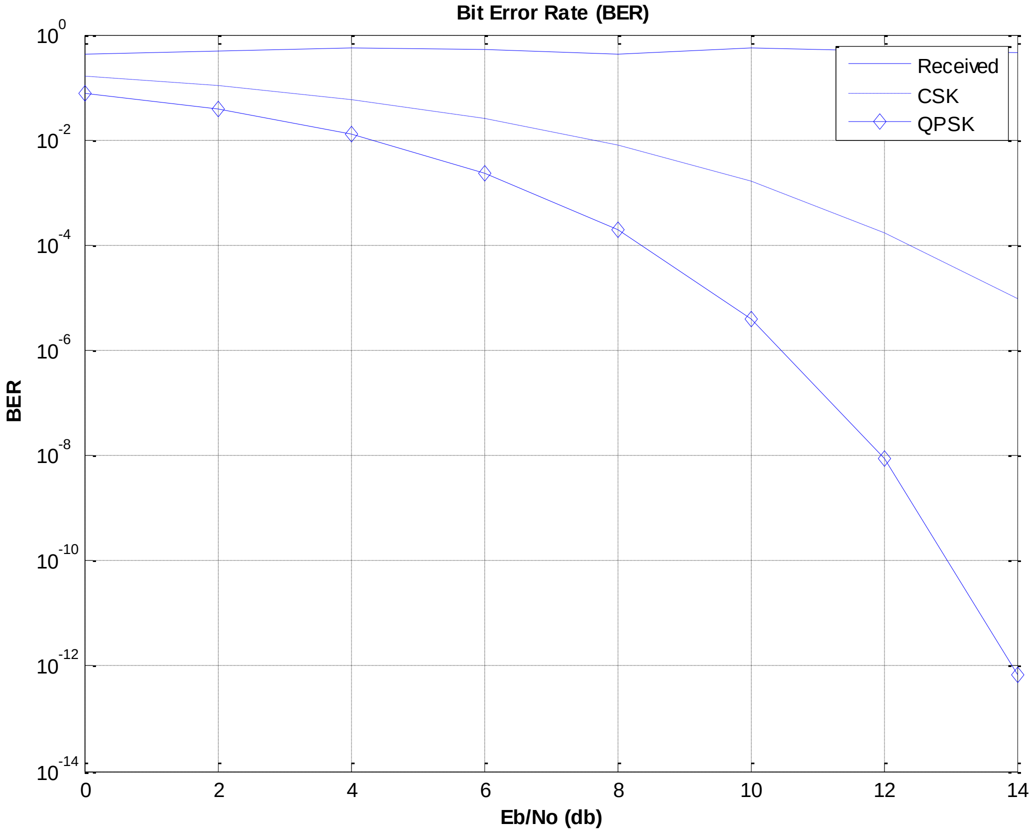


Figure: BER comparison

CHAPTER 6

PROPOSED METHOD OF CHAOTIC COMMUNICATION

6.1 Chaos based digital Communication Systems

One approach employed to achieve secure communications uses a chaotic signal to mask the sensitive information signal. In this approach, a synchronous chaotic system is used in the receiver to identify the chaotic part of the signal, which then is subtracted to reveal the information signal. Difficulties in this approach have been highlighted in the literature; however, several researchers have successfully demonstrated this approach in simulation and with hardware . Short investigated the level of security afforded by this approach, concluding that chaotic masking can offer some privacy but is not yet capable of providing a high level of communication security.

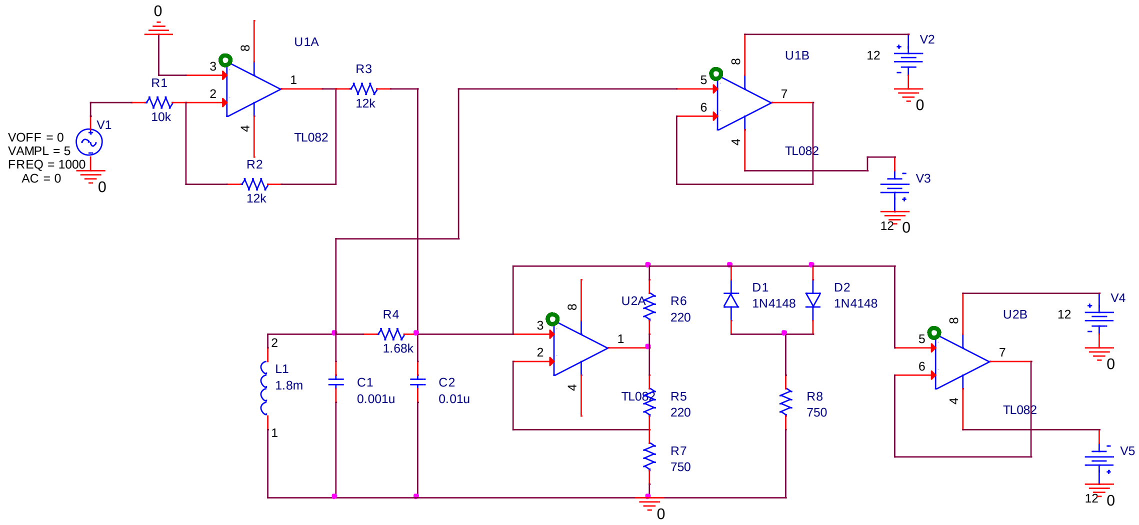
The general format of our approach is shown in Fig . In the transmitter, an analog information signal is encoded on the carrier using modulation of a parameter in the chaotic oscillator. In the receiver, a synchronous chaotic subsystem is augmented with a filter designed specifically to continuously extract the signal from the modulated waveform. Proper choice of drive channel and modulation parameter assures synchronization in the receiver, independent of the modulation.

6.2 The transmitter design

Widespread recognition that a theoretical chaotic communication system can be constructed from a chaotic circuit began in the early 1990s, and since then, various demonstrations. of a chaotic transmitter have be implemented. The fundamental understanding of the data modulation process, predicted effects and performance in different transmission channel conditions, and a limited amount of implementation criteria have been established. The chaotic phase shift keying modulation shows the greatest practical applicability to coherent communication system design, with theoretical Eb N0 performance approaching that of traditional PSK modulations and consists of a relatively simple modulation mechanism. This section focuses on the design and practical implementation of a chaotic phase shift keying transmitter that will form the first stage of the protoype coherent chaotic communication system. Since creating a chaotic waveform has been previously achieved, the emphasis is placed on creating efficient signal processing techniques that ensure the discrete-amplitude discrete-time chaotic sequence retains its maximal entropy characteristics once modulated and emitted. An evaluation of the analytical/simulated output waveform and comparison to measured hardware results is provided.

Practical implementation of the chaotic phase shift keying (CPSK) waveform requires signal processing techniques that compensate for timing uncertainty, fixed point arithmetic, and secondary effects of all operations. The end goal is to modulate user data in a manner that can be demodulated intelligibly at the receiver, yet be indistinguishable from bandlimited AWGN in the transmission channel. The burden of the signal acquisition and synchronization is placed on the receiver, which must contend not only with non idealities in its own hardware, but with the phase, frequency, and timing drifts that occur in the transmission channel.

6.3 The transmitter circuit



The transmitter, shown in Fig, is described mathematically by a dimensionless system of ordinary differential equations, which are

$$\frac{dx}{d\tau} = \alpha[y - (1+\gamma)x - \phi(x) + \gamma\lambda]$$
$$\frac{dy}{d\tau} = x - y + z$$
$$\frac{dz}{d\tau} = -\beta y$$

Where,

$$\phi(x) = ax + \frac{b-a}{2}(|x+1| - |x-1|).$$

the non dimensional independent variable is related to time as

$$\tau = \frac{t}{R_5 C_2}.$$

The dependent states are

$$x = \frac{v_{C1}}{V_{\text{on}}}$$
$$y = \frac{v_{C2}}{V_{\text{on}}}$$
$$z = \frac{R_5 i_{L1}}{V_{\text{on}}}$$

The various dimensionless parameters are defined as

$$\alpha = \frac{C_2}{C_1}$$
$$\beta = \frac{R_5^2 C_2}{L_1}$$
$$\gamma = \frac{R_5}{R_4}$$
$$a = \frac{R_5}{R_2} - \frac{R_5 R_7}{R_6 R_8}$$
$$b = -\frac{R_5 R_7}{R_6 R_8}.$$

6.4 The transmitter circuit Simulation(PSpice)

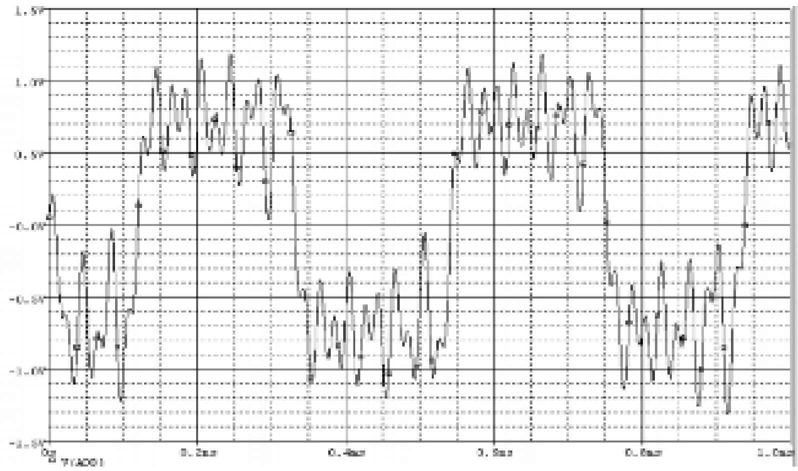


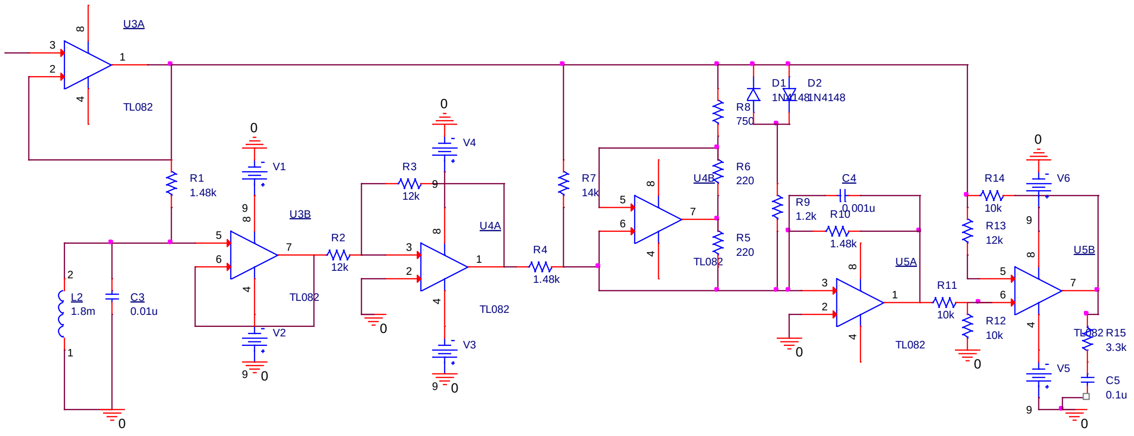
Fig: Graph of Transmitted Signal(Using Sinusoidal signal)

6.5 The Receiver design

The traditionally difficult task in implementing a coherent chaotic communication system has been satisfactorily synchronizing the chaotic circuits at the transmitter and receiver so that user data may be modulated, transmitted, and decoded efficiently. To date, there are believed to be no published chaotic circuit synchronization methods that are robust enough to provide the basis for a practical chaotic communications system. In fact, some1 have questioned the suitability of traditional control mechanisms like earlylate tracking loops for chaotic waveforms, while others have proposed iterative channel equalization methods as a solution to maintaining a robust chaotic circuit synchronization in varying channel conditions. This section outlines a prototype coherent chaotic communications receiver, including system-level architecture overview and comparison of predicted and measured performance. Detailed analysis leading to the core chaotic signal acquisition, chaotic circuit synchronization, and generalizations of direct sequence spread spectrum receiver processing is included .

A three-part paper by Kolumban, Kennedy, and Chua was published from 1997 to 2000, exploring the role, techniques, and performance bounds of synchronization in coherent chaotic communication systems. In general, coherent chaotic receivers can recreate exact duplicates of the chaotic sample functions used at the transmitter to modulate data; noncoherent receivers lack the ability to recreate or maintain a lock on all possible chaotic state evolutions experienced at the transmitter. Kolumban's work builds on the 1990 observation by Pecora and Carroll that chaotic systems can be synchronized, focusing on the need and limits that synchronization plays. One limit of this paper is the reliance on analog chaotic circuits, derived from variations of Chua's original chaotic circuits. The derived results significantly match those obtained in the simulation and hardware measurements for the chaotic communication system described in this dissertation, constructed using digitally generated discrete-time discrete-amplitude chaotic circuits

6.6 The Receiver circuit



The receiver, shown in Fig., is modeled nondimensionally as

$$
\begin{aligned}
\frac{dy_r}{d\tau} &= x - y_r + z_r \\
\frac{dz_r}{d\tau} &= -\beta y_r \\
\frac{dw_0}{d\tau} &= \alpha[y_r - (1+\gamma)x - \phi(x)] + kx - kw_0 \\
\frac{d\lambda_f}{d\tau} &= q_f\left[\frac{w_0 - x}{\gamma} - \lambda_f\right].
\end{aligned}
$$

In the dimensionless system, the dependent states are

$$
\begin{aligned}
y_r &= \frac{v_{C3}}{V_{\text{on}}} \\
z_r &= \frac{R_5 i_{L2}}{V_{\text{on}}} \\
w_0 &= \frac{v_{C4}}{V_{\text{on}}} \\
\lambda_f &= \frac{v_{C5}}{\gamma V_{\text{on}}}.
\end{aligned}
$$

The two filter constants are

$$
\begin{aligned}
k &= \alpha \\
q_f &= \frac{R_5 C_2}{R_{24} C_5}.
\end{aligned}
$$

6.6 The Receiver circuit Simulation(Using PSpice)

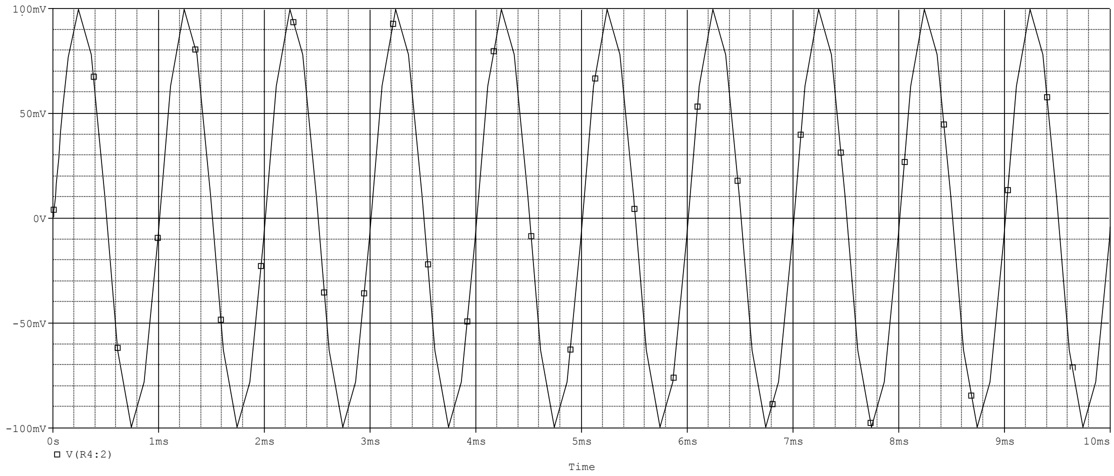


Fig: The received sinusoidal signal

6.7 Circuit Parameters

CIRCUIT COMPONENT VALUES AND DEVICES USED TO DEMONSTRATE COMMUNICATIONS WITH CHAOS

Component	Value or Device
L_1, L_2	1.8 mH
C_1, C_4	0.001 μF
C_2, C_3	0.01 μF
C_5	0.1 μF
R_1, R_2, R_{20}, R_{21}	10 kΩ
R_3, R_4, R_{11}, R_{12}, R_{14}, R_{22}, R_{23}	12 kΩ
R_5, R_{10}, R_{13}, R_{19}	5-kΩ potentiometer
R_6, R_7, R_{16}, R_{17}	220 Ω
R_8, R_{15}	750 Ω
R_9, R_{18}	1.2 kΩ
R_{24}	3.3 kΩ
U1, U2, U3, U4, U5	TL082, Dual BiFET Op Amp
D1, D2, D3, D4	1N914, Silicon Diode

6.8 Conclusion

A scheme capable of secure chaotic digital communication is presented and experimentally studied. Both the information input signal and the transmitted chaotic signal, are discrete (digital) signals. The chaotic nature of the transmitted signal was verified by its power spectrum, while the transmitter's chaotic mode of operation was checked by its BER calculation. In view of applications for this technology, we are concerned with the impact that channel effects will impart on this communication system. Specifically, amplitude attenuation, bandwidth limitation, phase distortion, and channel noise are effects that may be encountered in fielded systems. The popularity of chaos (and to a somewhat less extent its related fields of fractals and wavelets), is simultaneously a benefit and a detriment to its becoming an established subject worthy of serious consideration. On the one hand, this popularity finally brings an appreciation and interest from the general public for a highly mathematical subject that would normally be ignored by them.

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