Chapter 1

Introduction

1.1 What is Chaos ?

In our day to day life we encounter the term "Nonlinearity" in many ways. The electronic devices, circuits and systems are not an exception. Nonlinearity in the electronic devices is giving many surprising and fabulous results to the researchers from the past two decades.

Chaos is a nonlinear signal which made us to look back and change our perception. Many simulations and experiments have been done by many researchers to discover the way to generate chaos. Most of them are successful in generating chaos over Giga Hertz frequency band by using certain experimental set up of the circuits.

Chaotic signal are characterized well by using certain properties such as Lyapunov exponent (LLE), Kolmogorov Entropy (K2) and Fractal dimension (D2). Lyapunov exponents tell us the rate of divergence of nearby trajectories which is a key component of Chaotic dynamics. The Kolmogorov complexity of an object, such as a piece of text, is a measure of the computability resources needed to specify the object. Fractal dimension is a ratio providing a statistical index of complexity comparing how detail in a pattern changes with the scale at which it is measured.

In our experiment we have generated a Chaotic signal in microwave frequency band by using single microwave transistor namely BFU725F/N1 with essential experimental set up in order to excite with microwave source. BFU725F/N1 is a NPN silicon germanium microwave transistor which has a noise figure of 0.7dB at 5.8 GHz. It has a maximum stable gain of 27dB at 1.8 GHz. By exciting with microwave source and operating the transistor in its nonlinear region giving rise to the generation of chaos in microwave frequency band.

1.2 Application of Chaos

A promising application of Chaos is mainly as a provider for carrier signals in secure communications. The main reason to do so is its extreme sensitivity. The importance of chaos in secure communications has been explained by Chua and other people in the past and they have been successful in implementing it.

1.3 Objectives of this Work

The specific objectives of this work can be summarized as:

- To generate a chaotic signal using simple microwave circuitry.
- To ensure the circuit simplicity, reliability and tunability.

1.4 Thesis Outline

- Introducing the basic principles of chaos and relevant analysis tools and techniques namely iterative map, cobweb plot, Largest Lyapunov Exponent(LLE), Fractal Dimension (D2), Kolmogorov entropy (K2), Phase Portrait and Distance Plot which are used as standard parameters for characterization.
- An iterative map representing chaos with a signal dependence is formulated.
- This iterative map is characterized using cobweb plots for different **'r'** values.
- A hardware based implementation of Chaos generation is performed and standard characterization is done.
- In order to evaluate the tunability of the proposed chaos, waveforms for different **'r'** values are obtained and evaluated.
- The variation of the **'r'** values gives rise to an interesting phenomenon called **"Chirping"** which is studied using Microwind in 180nm CMOS technology.

Chapter 3

Generation of Chaos

3.1 Experimental Setup

In our experiment we have generated Chaotic signal in microwave frequency band by using single microwave transistor namely BFU725F/N1 with essential experimental set up in order to excite with microwave source. BFU725F/N1 is a NPN silicon germanium microwave transistor which has a noise figure of 0.7dB at 5.8 GHz. It has a maximum stable gain of 27dB at 1.8 GHz. By exciting with microwave source and operating the transistor in its nonlinear region giving rise to the generation of chaos in microwave frequency band.

The nonlinear region of the transistor is identified from the datasheet which the I-V graph showing its different characteristics.It is as shown in Fig 3.1.

3.2 Methodology

A simple experimental setup consisting of microwave source, BFU725F/N1 NPN microwave transistor and a function generator is shown in Fig 3.2. The base terminal of the BFU725F/N1 transistor has been connected to the Gunn power supply through Isolator, PIN Modulator, Adaptor and Test Gig. A function generator has been connected to the emitter terminal of the transistor. Output will be measured at the collector terminal of the transistor by using oscilloscope.

The generated chaotic signal has been analyzed by using MATLAB tool in order to obtain values for its properties such as Fractal dimension (D2), Kolmogorov complexity (K2) and Lyapunov exponent (LLE).

Here the signal generated by function generator was kept constant at 1MHz and Gunn bias voltage has been varied from 5.22 to 9.03 volts.The range of operation from 6.82 to 9.03 volts has been identified as the Negative Resistance Region which results in signals in microwave region (X-Band). At the collector terminal the 'r' dependent chaotic signal has been observed using the oscilloscope.The results have been tabulated in Table 3.1.

Table 3.1: Tunability based on Bias Voltage Variation

Input	Bias voltage (Volts)	Bias Current (Amperes)	LLE	K2 (Nats/s)	D2
1	5.22	0.286	NA	NA	NA
2	5.43	0.293	NA	NA	NA
3	6.02	0.345	1.137	6.8737	0.7925
4	6.82	0.345	0.5921	7.1516	0.7925
5	7.05	0.343	5.0229	6.9323	0.7925
6	8.01	0.342	1.5186	7.1453	0.7925
7	9.03	0.335	2.0482	7.1425	0.7925

In the table, only from the 6.02 volts the bias current starts to decrease. This is due to Gunn Effect which gives rise to the Negative Resistance region of Gunn Diode operation. As we are interested only in Microwave signals which are obtained in this region, only they are characterized.

Overlap of spectra for output showing its nonlinear nature and the Gunn diode source spectrum is shown in Fig 3.2.

The waveform for the envelope of the generated chaos obtained as a voltage signal for the bias voltage of 9.03 volts has been studied and is shown along with the phase plane plot in Fig 3.3 and Fig 3.4.

This waveform is evaluated with different parameters as mentioned above.

Different output waveforms are generated for different bias voltages which can be shown below and their chaotic behavior has been characterized as well. The Waveforms, Phase Portraits , Polar Plots for different inputs is given below.

3.3 Conclusions from figures

Bias Voltage Variation Table

From the table, we can see that the Largest Lyapunov exponent has increased and is positive down the table. This shows that maximum chaotic behavior is obtained when the bias voltage is maximum in permissible limits. Interestingly, K2 has decreased down the table which has shown that the entropy decreases when the effect of Bias Voltage on the Gunn diode increases. But, the fractal dimension of the system (D2) has remained constant which shows the unchanging scale of the system output.

Waveforms

The effect of the chaotic nature or nonlinear nature that is ascribed to the output waveforms has increased with the increase in the bias voltage in Negative Resistance Region. This may be due to the fact that effect of transistor increases with the increase in the Gunn Bias voltage. So, we can safely say that the nonlinearity that is obtained at the output has been mostly due to the transistor.

Spectral Overlap

The nonlinear nature of the transistor has included a number of new harmonics into the spectrum of output signal. The initial Gunn diode source spectrum has only one peak which is apparent in Fig 4.3 (shown as bottom curve). Due to the attribution of the nonlinearity by the transistor we can see there are two peaks and two nulls in the place of on peak. There subharmonics added below 8GHz and superharmonics added above 10GHz clearly showing that effect.

Polar Plots

The polar plots show the phase related information of the waveforms. The conclusion that was arrived from observing them is that the information available has been equally distributed along all phases of the signal which considerably increases the entropy which is observed to hold true by calculations of the Kolmogorov Entropy(K2) than the Gunn source spectrum.

Phase Portraits

The phase portraits of all the waveforms show the presence of focii around which the signal characteristic curves oscillate. This means that all the observed signals' phase portraits have "Attractors" which are stable points which govern the chaotic behavior of the system. This conclusively proves all the obtained waveforms are chaotic which is interesting because they exist in the microwave region and are obtained using simple microwave circuitry which is the objective of this work.

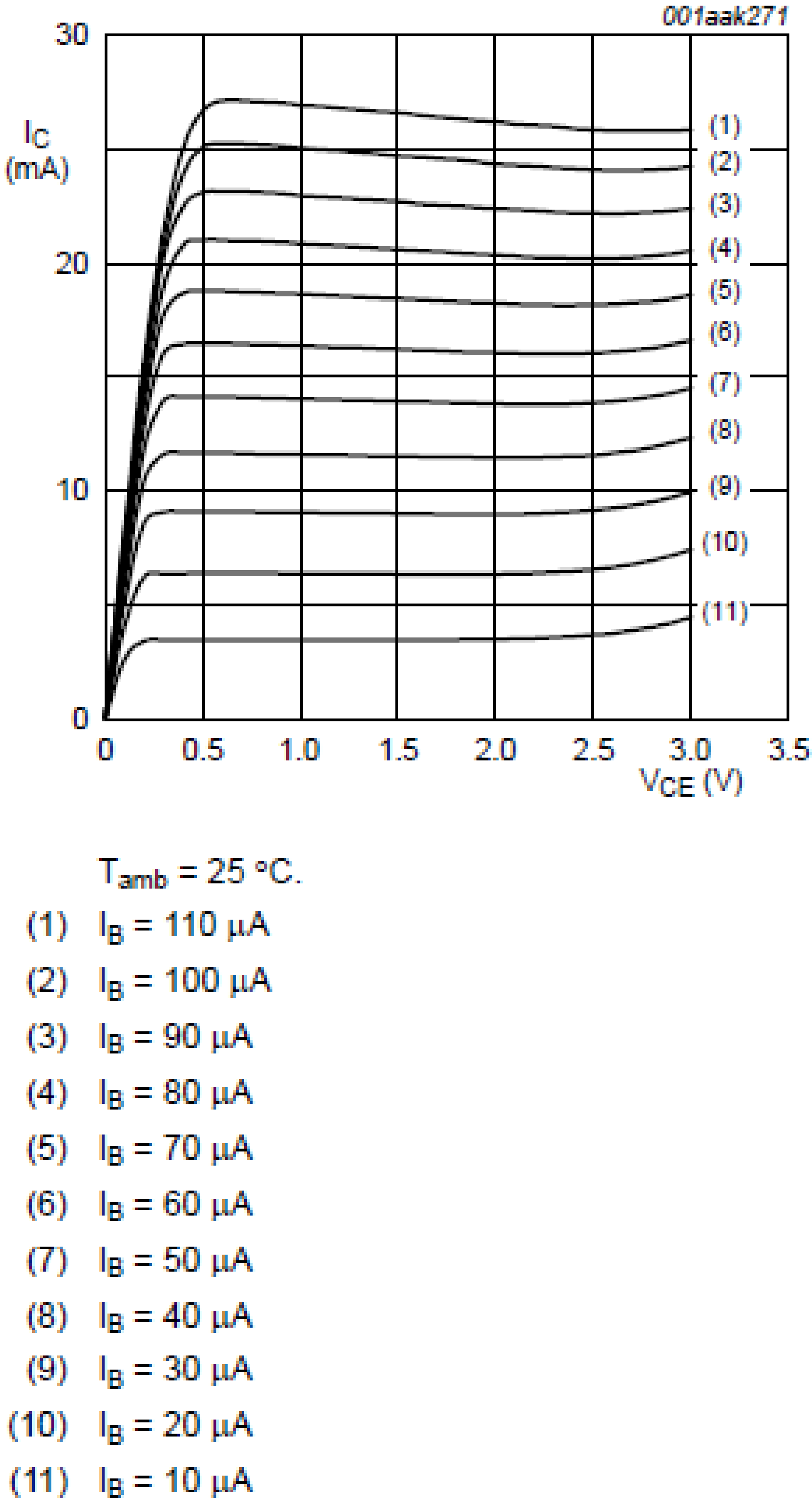

Figure 3.1: Collector current as a function of Collector-Emitter Voltage; typical values

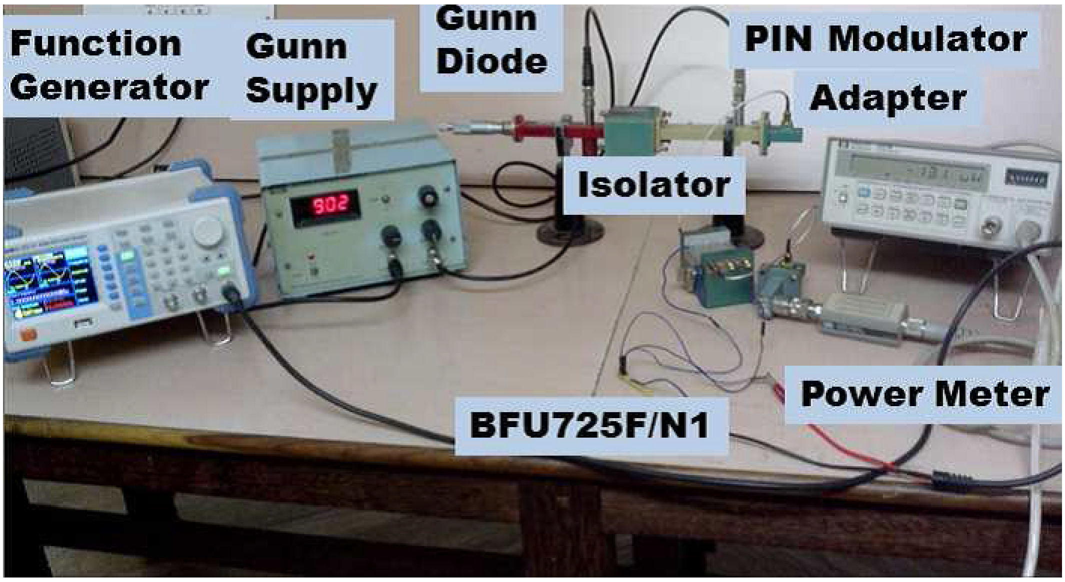

Figure 3.2: Experimental Setup for Chaos Generation

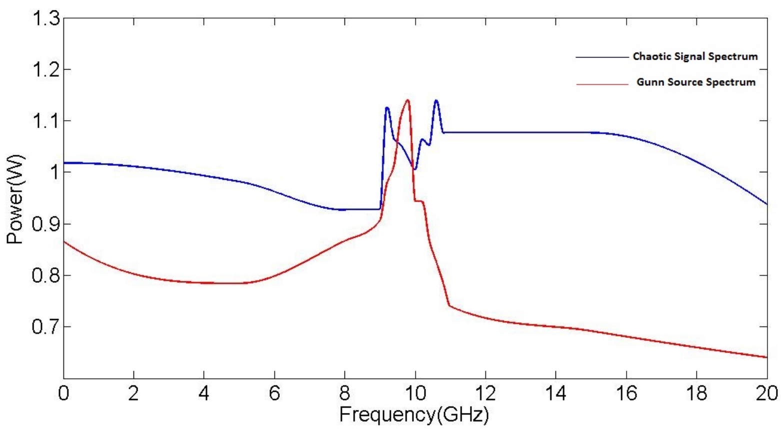

Figure 3.3: Spectral Overlap of Gunn and Chaotic Signal

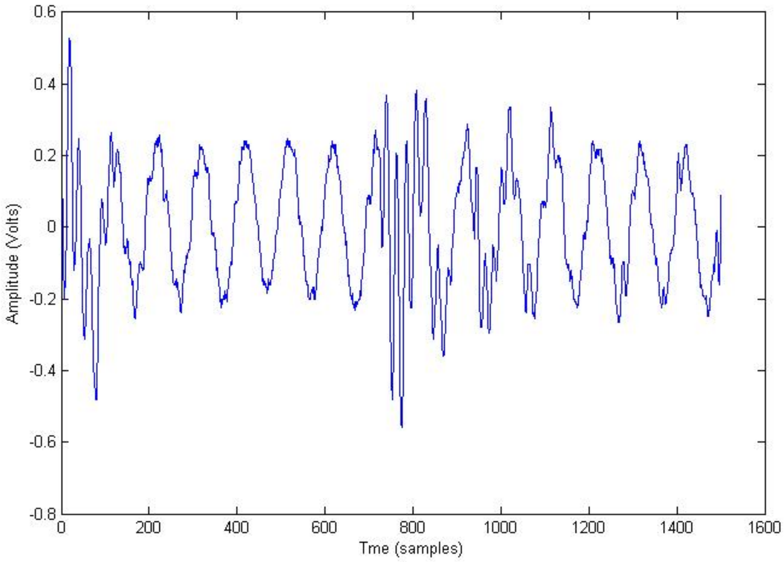

Figure 3.4: Waveform of Output Chaotic Signal

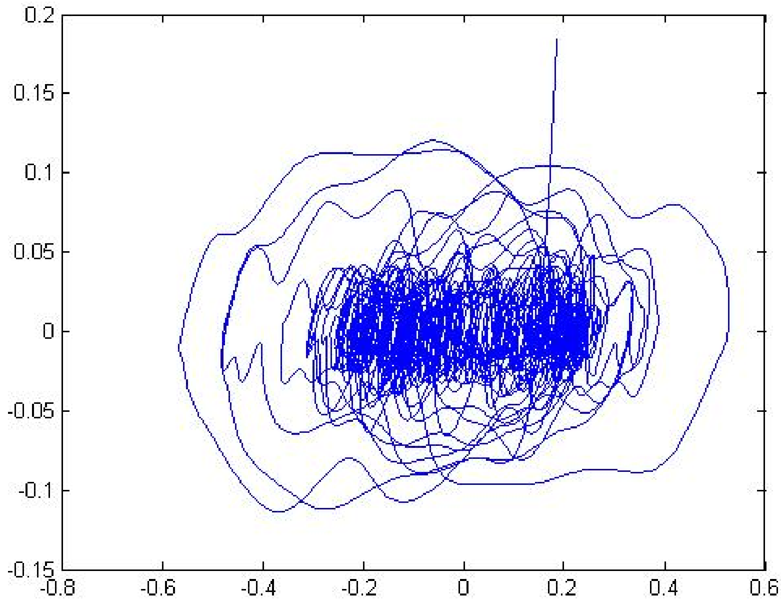

Figure 3.5: Input 7 Phase Portrait

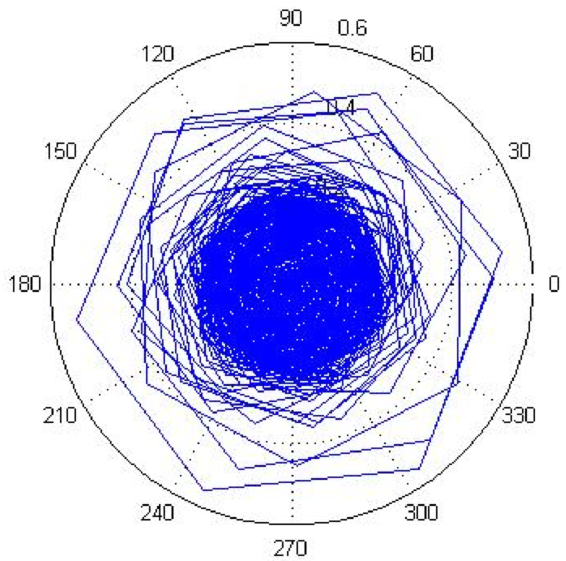

Figure 3.6: Input 7 Polar Plot

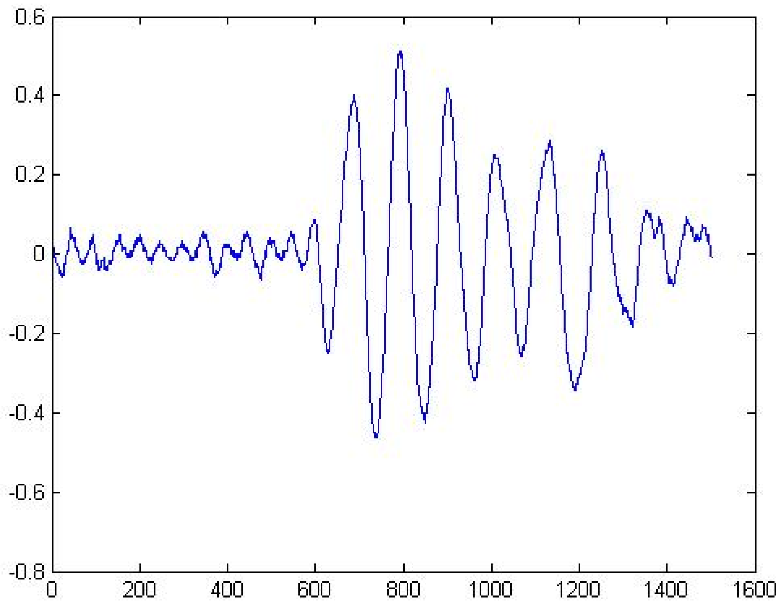

Figure 3.7: Input 3 Waveform

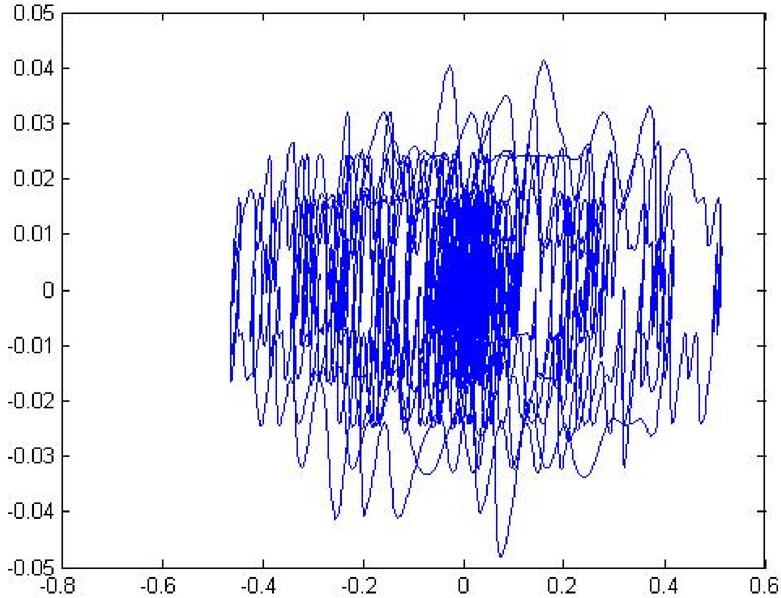

Figure 3.8: Input 3 Phase Portrait

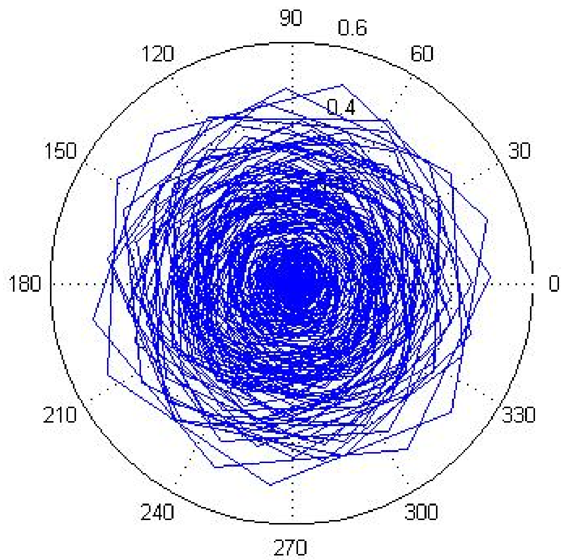

Figure 3.9: Input 3 Polar Plot

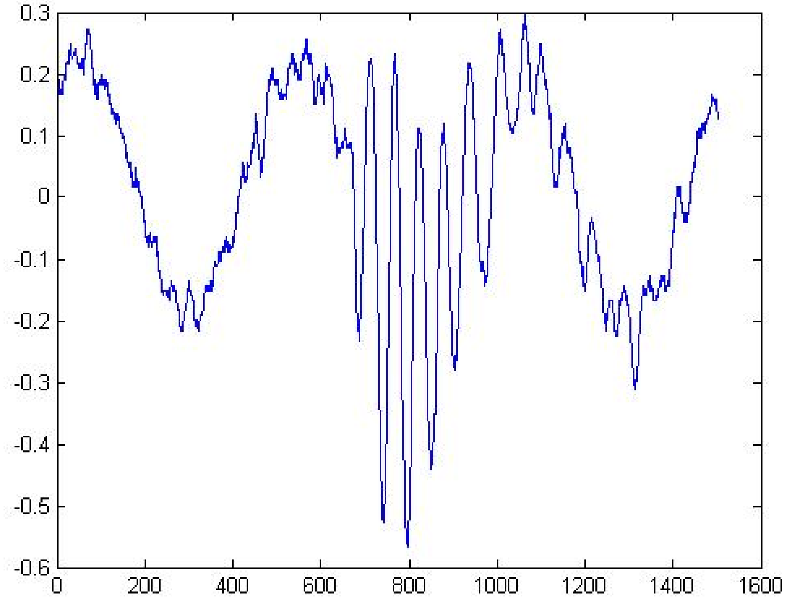

Figure 3.10: Input 4 Waveform

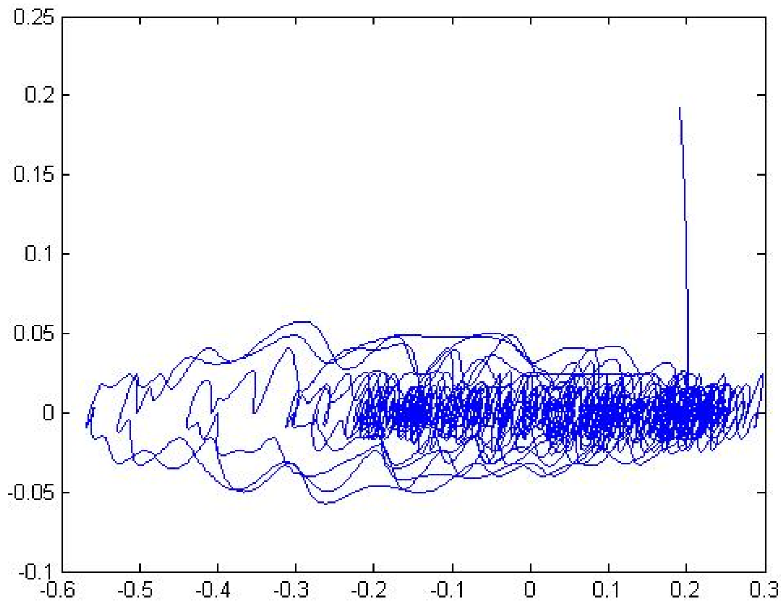

Figure 3.11: Input 4 Phase Portrait

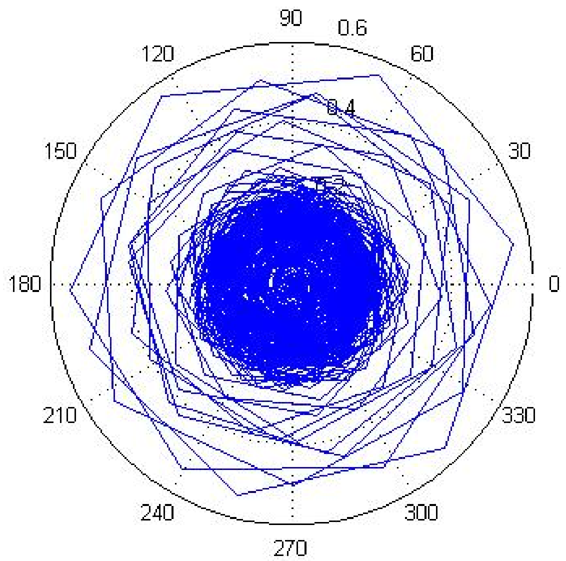

Figure 3.12: Input 4 Polar Plot

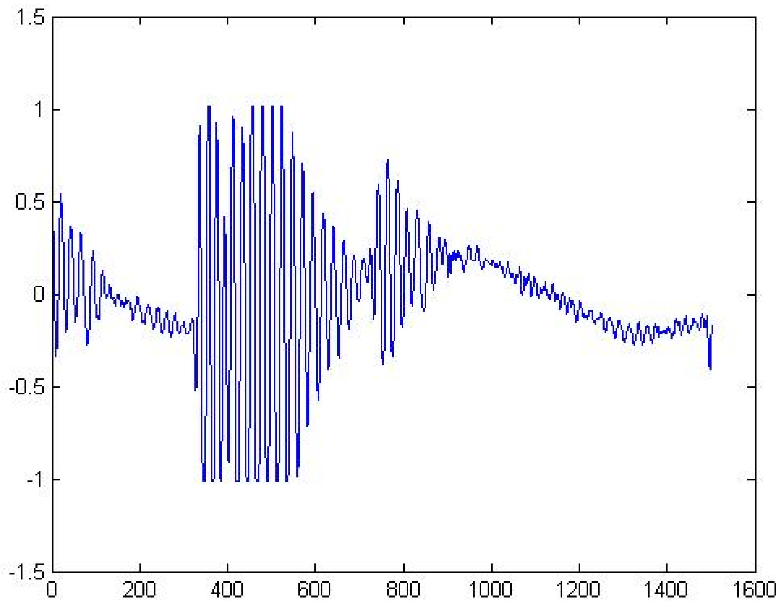

Figure 3.13: Input 5 Waveform

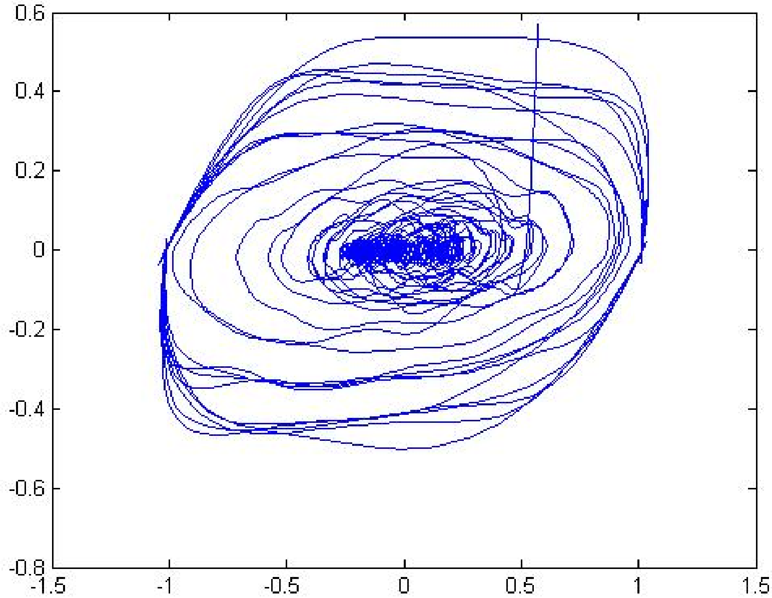

Figure 3.14: Input 5 Phase Portrait

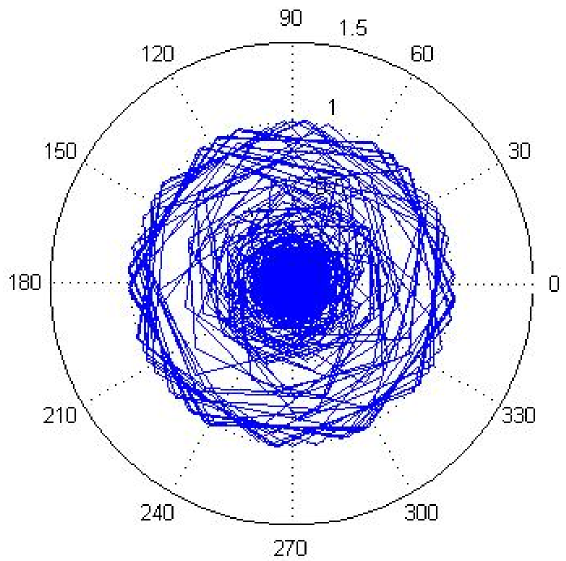

Figure 3.15: Input 5 Polar Plot

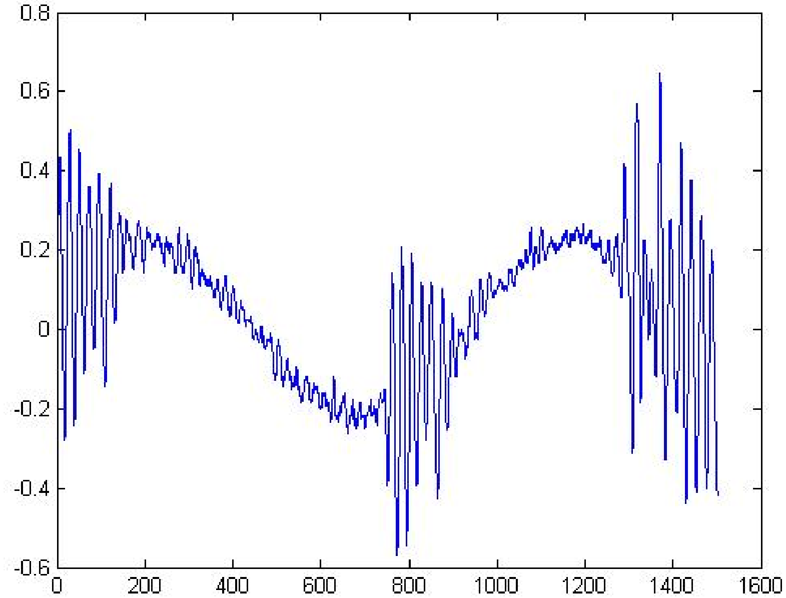

Figure 3.16: Input 6 Waveform

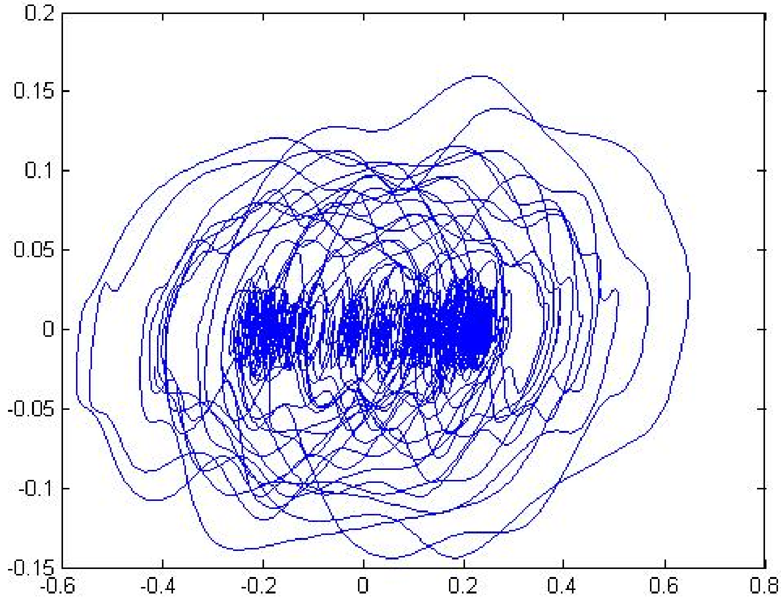

Figure 3.17: Input 6 Phase Portrait

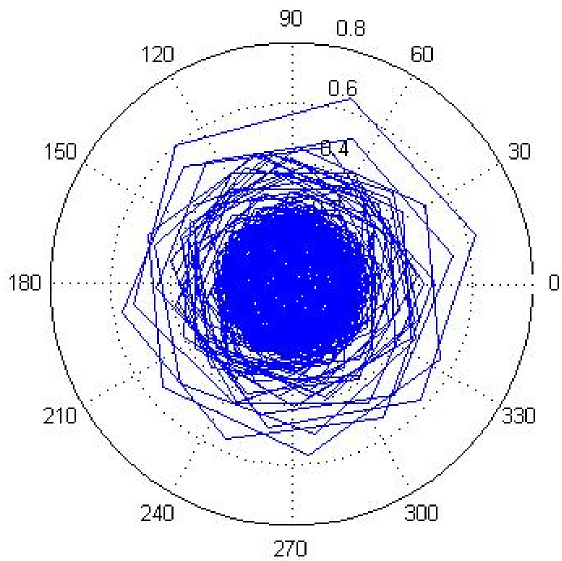

Figure 3.18: Input 6 Polar Plot

Chapter 5

Conclusion

The following section reiterates the key thoughts and results derived from the work explained in earlier chapters.

5.1 Inferences

- Two fundamental concepts of Chaos - Nonlinearity and Sensitivity are elaborated.
- The proposed chaos has been illustrated as an iterative map.
- The three key parameters of the iterative map namely "y", "r", "K" are studied.
- Standard parameters for characterization of a system's chaotic behavior are introduced and studied.
- An implementation of the methodology to generate chaos using simple microwave circuitry is done using a single transistor.
- Microwave characteristic is retained in implementation by identifying the Negative Resistance Region in which the Bias current decreases when Bias Voltage increases.
- The system is made to operate in this Negative Resistance Region for generating chaos in X-Band.
- The tunability and sensitivity are tested by using the variation of the bias voltage of the Gunn source.
- The simplicicty is retained by the use a single transistor in the system and observing its natural reponse to the given inputs.

- The waveforms are analyzed using MATLAB tool for calculation of LLE, K2 and D2 for characterization of observed chaotic behavior of the system.
- The system is developed for CMOS technology in software simulation and results were compared.
- An exciting phenomenon called **"Chirping"** is observed, which is well characterized and the results are documented.

5.2 Future Work and Use

This work helps to promote more cutting edge technology which helps us to explore an unknown territory which shows what can be achieved using simple circuits which give results that are previously thought to be possible only with complex systemms. This also reduces lot of problems genrated by complex systems such as self heating, system degradation and high cost.

Another important avenue that is opened up by this work is the **Chirping** phenomenon which was previously possible by highly expensive and sophisticated systems like "Chaotic Lasers" etc. There is a possibility that if this work is pursued further many more exciting possibilities open up in the areas such as **Secure Communication** as a provider for "Signal Carriers" and "Chirplets" which are being used in **Signal Processing and Analysis**.

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