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HIGH FREQUENCY CHAOS IN DIODE RESONATOR AND ITS CONTROLS

Md. Moinul Islam[1], Deepak Pandit[2], A De[3] and Srijit Bhattacharya[1,*]
Department of Physics, Barasat Government College,Kolkata-700124, WB, India.[1]
Variable Energy Cyclotron Centre, 1/AF Bidhannagar, Kolkata-700064, WB, India[2]
Department of Physics, Raniganj Girls' College, Raniganj, Burdwan- 713358, W. B., India.[3]
srijit.bha@gmail.com[1,]*

Abstract: The chaotic dynamics of different diodes (1N4007, 1N4148, green light emitting diode and zener diode) in R-L-D circuit (R=1k Ohm, L=100mH) is studied at higher frequencies (1.6kHz-20kHz) and constant input voltage (3Vp-p). A novel but simple technique is shown to measure diode reverse recovery time based on its chaotic dynamics. The experimental outputs of R-L-D circuit are found in agreement with the PSPICE model simulation, except in 1N4148. The chaos involved is confirmed by the bifurcation plot and Lyapunov exponents. This technique could facilitate the fabrication of fast and ultrafast diodes. Finally, two simple but elegant experimental methods are demonstrated to control chaos in R-L-D circuit.

Keywords: *Chaos, R-L-D, reverse recovery time, frequency, PSPICE, control of chaos, Lyapunov exponent*

I INTRODUCTION

Non-linearity and chaos are ubiquitous in science and technology. Applied sciences e.g secure communication, cryptography, applied biology like brain dynamics, cardiac rhythm etc [1, 2] have been aided tremendously by nonlinear science. Ardent research works have been focused on nonlinear resonating oscillator circuits comprising of p-n junction diode (D), resistor (R) and inductor (L) to understand the general behaviour of chaos [3, 4, 5]. Chaos is highly important in both low and high frequency (f) domains [6,7]. Hence the chaotic behaviour of *R-L-D* circuits, depending on the 'memory' effect due to the reverse recovery time (τ_{RR}) of p-n junction diode, is required to be well-understood for better performance of electronic circuits at different input frequency regions. In the past, generally, the chaotic behaviour of the varactor diode has been studied by varying the amplitude of the input sinusoidal signal [3, 4, 8]. However, τ_{RR} is not a function of input voltage alone. De Moraes and Anlage [3] suggested that, τ_{RR} (for diodes *1N4007*, *1N5400*, *1N5475* and *NTE610*), should be a function of input driving frequency, DC offset, duty cycle and circuit resistance. This paper, for the first time, investigates the *f*-dependency of τ_{RR} of diodes. Here, to confirm the chaotic nature, the experimental bifurcation diagram has been plotted. Besides, Lyapunov exponent (λ) has also been estimated in this work.

In the present work, a novel technique is introduced to measure τ_{RR} of a diode utilizing the chaotic properties of R-L-D circuit. In this method the parameters of diodes *1N4007* and *1N4148*, 6.8V breakdown zener diode *BZX85C6V8*, and green light emitting diode i.e *LED* are investigated varying the driving frequencies. Two simple methods are also initiated to control the chaos involved in *R-L-D* circuit. Although chaos control in *R-L-D* is essential for superior performance, practical chaos control is very rarely studied in such circuit.

II MATERIALS AND METHODS

The experimental circuit, shown in Fig. 1, consists of a resistor R=1kΩ, inductor L= 100mH and a p-n junction diode driven by a sinusoidal waveform. The sinusoidal voltage is obtained from a 100Hz-1MHz function generator with 50Ω transmission line output. The output voltage across L (V_L) is checked using the online oscilloscope facility of ExpEyes kit developed by IUAC, India. The kit is computer interfaced and powered by USB port of the computer (*http://expeyes.in/*). A four channel oscilloscope is enabled in the interface with maximum sampling rate of 250kHz. The response of the circuit is also simulated by Orcad PSPICE simulator student version (www.orcad.com/products/orcad-pspice-designer).

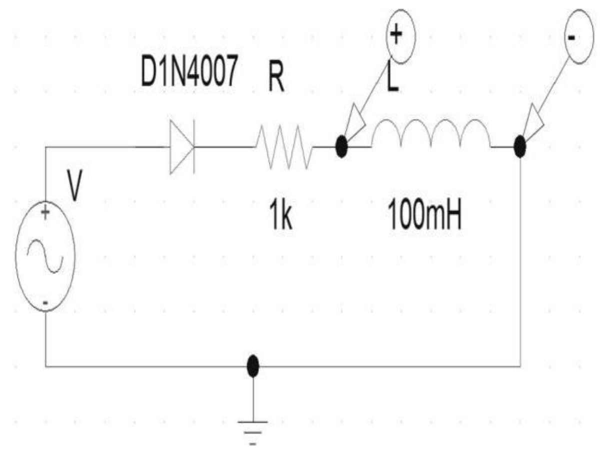

Figure 1 The R-L-D circuit diagram.

III EXPERIMENTAL RESULTS

3.1- Frequency driven chaos

A *R-L-D* circuit behaving as series *R-L-C* circuit resonates at a frequency of f_0=26.5 kHz. The frequency-driven dynamics is studied near this resonating frequency. V_L shows only one peak with no bifurcation above f=15.0 kHz. Thereafter period-2 bifurcation can be seen. At input frequencies 8.0 kHz onwards, the output moves into period-4. Higher bifurcations arise on lowering the frequency further. The detail is given in Table 1. In Fig.2, the panels A, F and E are the experimental oscilloscope outputs at f=15, 8.0 and 3.8 kHz, while panels B, C and D are corresponding PSPICE simulated outputs. The experimental output is found to be in complete agreement with PSPICE simulation. To confirm the chaotic dynamics involved, we estimated the experimental bifurcation diagram and Lyapunov exponent. The experimental bifurcation diagram, keeping the driving frequency as a parameter, is shown in Fig.3. The period multiplication can be seen clearly at f=15, 8 and 3.8 kHz.

3.2- Technique for measuring τ_{RR}

A unique technique for measuring τ_{RR} of the diode is adopted in this work. Reversing a forward biased diode very abruptly, takes finite amount of time τ_{RR} to release the stored charge. Therefore, due to those unrecovered charges from the negative half up to the next positive half cycle of the output voltage (V_L) the state fluctuates (positive to negative) so many times depending on the driving frequency and τ_{RR}. Dividing the time duration within which the diode repeatedly changes state by the number of bifurcations (shown as peaks) appearing in the said duration, τ_{RR} is estimated. In the panels A and B of Fig.2, the process of measuring τ_{RR} is depicted very clearly. In the panel A, the time interval, shown by an arrow, is approximately 16 μs and the number of bifurcation peak is 1 within it.

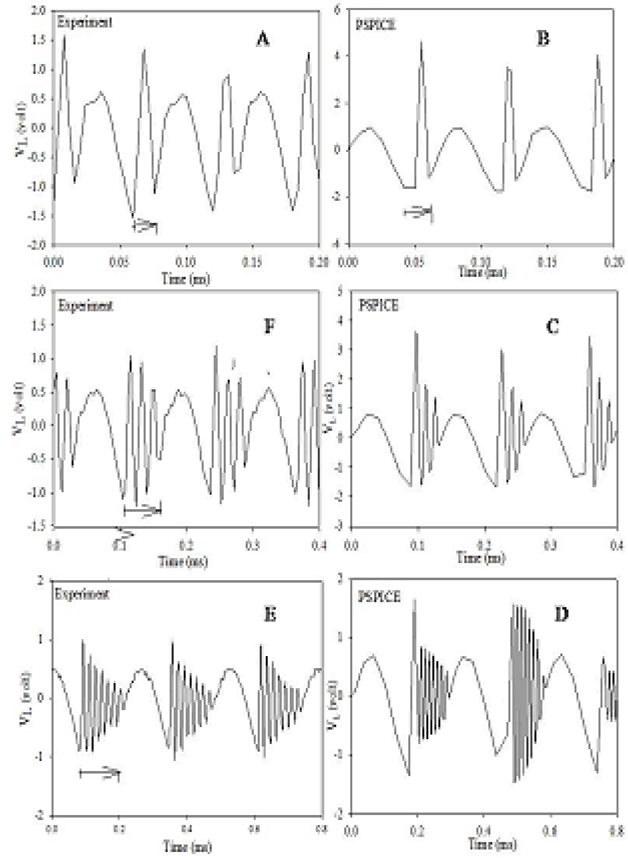

Figure 2 Panels A, F and E: Oscilloscope output V_L at f=15, 8 and 3.8kHz, respectively, for diode 1N4007. Panels B, C and D: Corresponding PSPICE simulations. The panels A, F and E indicate the time interval for measuring τ_{RR} using an arrow.

So, τ_{RR} is 16μs/1 peak=16 μs. Similar value of τ_{RR} is also obtained from the PSPICE simulation in panel B. In the panel F for period 4 bifurcation, the time interval 56μs is divided by the number of peaks. Therefore, τ_{RR} =56μs/3 peaks=19μs (approx) and similar value is also obtained from PSPICE simulation (panel C). For period-8 bifurcation, shown in panel E we get, τ_{RR} = 132 μs/7 peaks=19 μs (approx). Using PSPICE simulation the calculation of τ_{RR} is extended up to f= 200 kHz. The simulated data of τ_{RR} is fitted against driving frequencies and found to be dependent on $f^{(-0.29\pm0.14)}$ (fitted line is shown as dashed line in the fig. 4). The correlation coefficient (r^2) of the fit is found to be 0.91.The experimental data is also plotted in the same figure. Frequency-driven chaotic dynamics of zener diode *BZX85C6V8* and *1N4148*, and green light emitting diode (*LED*) is also investigated in the same way and the values of τ_{RR} are given in table 1.

To understand the degree of chaos, the Lyapunov exponent (λ) is also calculated from time series data and mentioned in table 1.

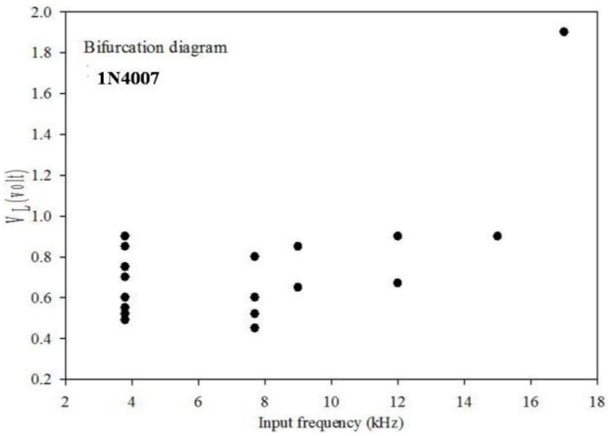

Figure 3 : The bifurcation diagram for diode 1N 4007.

3.3-Control of Chaos

Often chaos is undesirable in many practical cases. So the idea of control of chaos is highly important. In the *R-L-D* circuit mentioned in this paper, we have controlled chaos using two different methods. In the first method, as shown in [9], a dc voltage source (V_2) is connected additionally with the *R-L-D* circuit. The dc input voltage is taken as 1.53V for 1N4007 and the peak to peak value of the sinusoidal input voltage (V_1) is taken as 3V. The circuit diagram is given in the top panel of Fig.5. The output voltage (Fig.5 bottom panels) shows suppression of chaos for V_2=1.53V. Chaos suppression is not possible below that voltage.

In the second method, a sinusoidal voltage source (V_2) is connected in addition to the one (V_1) that is already applied in the *R-L-D* circuit. Fig.6 top panel shows the corresponding circuit and bottom panels A and B give the simulated and experimental outputs, respectively. The output voltage V_L is now chaos free, although this time it looks like a half-wave rectifier output.

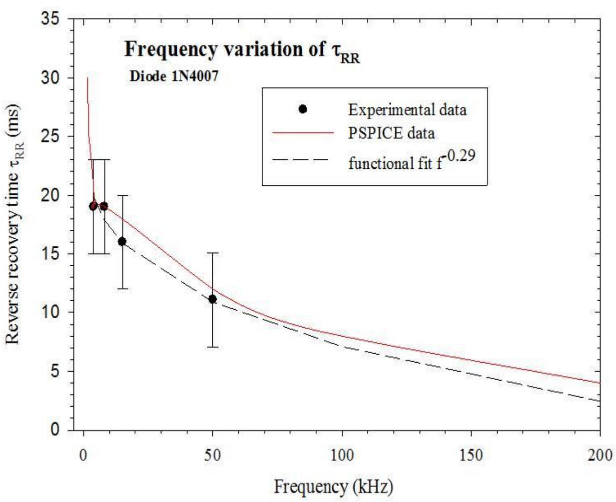

Figure 4: Input frequency variation of τ_{RR} in diode 1N4007. Solid line is PSPICE data, dashed line is functional fit and filled circles are from experiment.

IV DISCUSSIONS

In this paper, using the frequency driven chaotic dynamics of *R-L-D* circuit, different diodes have been tested and the dependence of their reverse recovery time on input driving frequency of sinusoidal waves have been measured, both experimentally and theoretically. It could be reaffirmed that, very rarely, such an investigation was done the past. In our work a new technique has been introduced to measure the reverse recovery time of a diode using the chaotic framework.

Using the τ_{RR}, the values of junction capacitance C_{J0} is also determined following the equations given in [10] and corroborated with the measurement done by a HIOKI LCR meter IM 3536. The input ac voltage is taken as only 15mV, dc voltage remaining zero. The zero bias capacitance (C_{J0}) is found to be 19*pF* for the diode *1N4007*. Besides diffusion capacitance (C_d) is also calculated as per [10] and given in table 1.

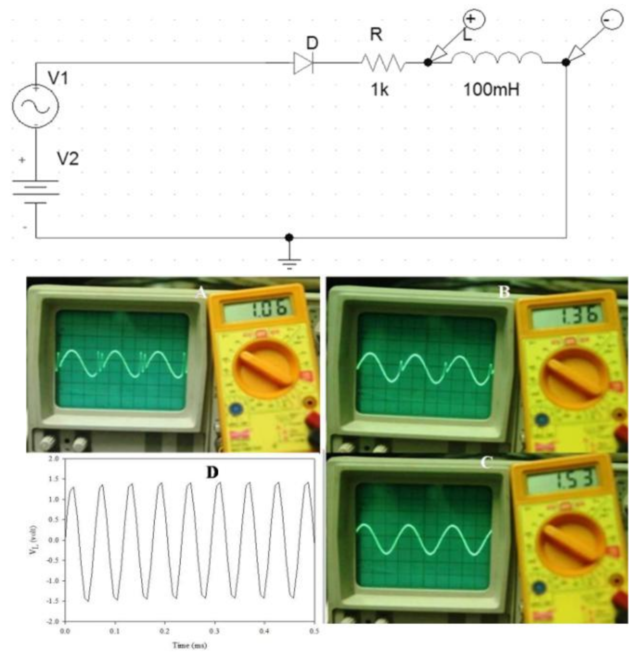

Figure 5: top panel: The circuit diagram for chaos control under method 1 as described in manuscript. Bottom panels: The demise of chaos for V_2=1.53 V. The chaos free output V_L is shown in bottom panels C and D (experimental and simulated outputs, respectively).

The PSPICE simulation of *f*-driven chaos in diode 1N4148 disagreed with the experimental data. This could be due to the high speed switching ability of the diode. The positive values of λ indicates chaotic dynamics involved in the circuit.

The knowledge on the non-linearity introduced by τ_{RR} is essential to use diodes in high density electronic circuits. Off late, avid research work is going on to prepare fast and ultrafast diodes using different kinds of material like p-p-i-n-n + GaAs. In this context any simple method to measure τ_{RR} will be an added advantage [11].

IV CONCLUSIONS

R-L-D circuits are essential to understand chaos. In this work, the driving frequency dependent chaos in *R-L-D* circuit has been investigated and the bifurcation diagram along with Lyapunov exponent (λ) has been presented at different frequencies to confirm chaotic nature. A new technique has been described here to find the reverse recovery time τ_{RR} of different diodes by both experiment and PSPICE simulations. Using this technique, τ_{RR} of a diode can be measured very easily and accurately without constructing any complicated circuits. This would benefit the fabrication of fast and ultrafast diode immensely. The frequency driven dynamics of diode has rarely been studied in the past. Besides, the ways to suppress strong chaotic motion in R-L-D circuit have also been accounted for in this work.

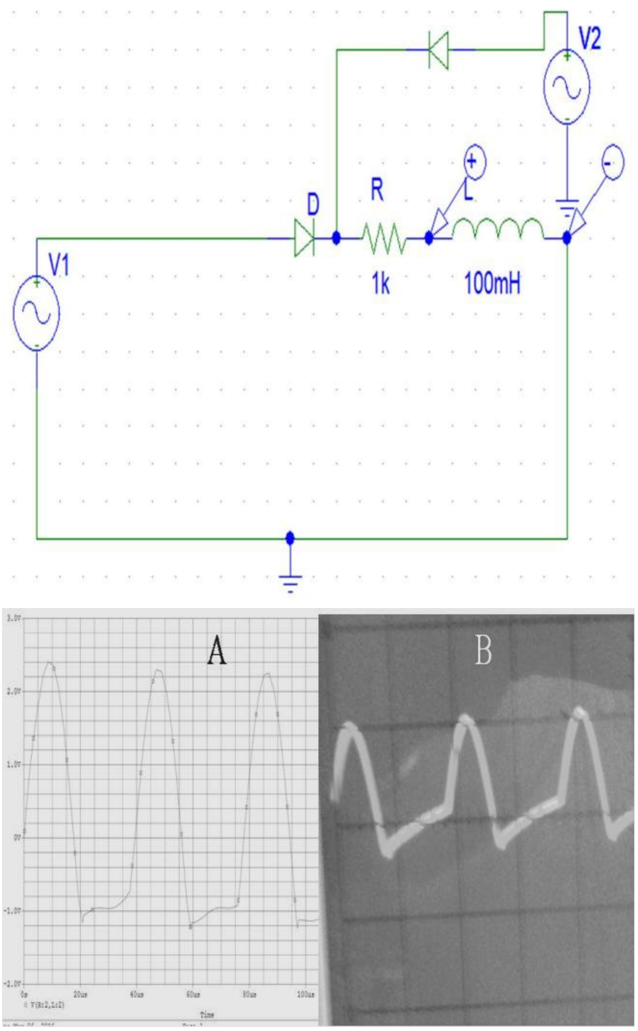

Figure 6: top panel is the circuit diagram for chaos control as per method 2 described in manuscript. Bottom panels A and B are PSPICE and experimental outputs, respectively.

Table 1: Chaotic Dynamics and Different Parameters of Diods

Diode	Freq(f) kHz	Period	*Cd* pf	τ_{RR} μs	λ
1N4007	15.0	2	361	16	0.307
	8.0	4		19	1.070
	3.8	8		19	1.538
BZX85 C6V8	10.5	2	390	38	0.543
	4.0	4		39	0.135
	2.0	8		42	1.585
1N4148	18.0	2	280	12	0.496
	8.7	4		14	1.183
	4.0	8		15	1.54
Green LED	16.0	2	138	8	-0.123
	13.8	4		12	0.776
	5.9	8		15	0.525

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