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Chaotic Behaviour in a Twin-T Circuit

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***Abstract*-This paper examines a driven nonlinear circuit that generates chaotic signals. The circuit is very simple, requiring just one op-amp stage. Only off-the-shelf components are required to construct the circuit. The circuit must be driven by a low frequency input-signal. The shape and frequency of the signal affects the behaviour of the chaotic waveforms. A variety of unusually folded attractors have been observed from the practical circuit.**

I. INTRODUCTION

The twin-T sub-circuit is well known, and is often used in oscillators and notch filters [1]. This kind of circuit can become unstable at very high Q settings. This circuit exploits the inherent instabilities of tuned twin-T circuits and introduces a light emitting diode as the nonlinear element and tuned resistor for one T section. This results in a variety of chaotic phenomena that can be easily and reliably obtained.

No special components are necessary in the construction of this circuit, nor are there any critical values to strictly comply with. The circuit will become chaotic with a variety of different signals although triangle, saw- and sine-waves produce cleaner outputs. Square-waves and pulses can result in the output bouncing off the power rails which clips the signal. Introducing DC offset input signals or signals with multiple breakpoints results in multiple wells and chaotic patterns of increased complexity.

II. CIRCUIT DESCRIPTION

The circuit under study was designed by T. Escobedo to perform as an audio filter [2]. I. Fritz observed the circuit displays chaotic phenomena under certain conditions [3].

To optimise the circuit for observing chaos, the resonance rheostat was changed from the original design specifications, to 1kΩ and the external control voltage input was omitted. A high resonance setting is required for chaos to occur, it is possible for the resonance rheostat to be removed and replaced with a link or low valued resistor (<200Ω). Increasing the resistance beyond 1kΩ causes the circuit to deliver bursts of high frequency oscillations.

A second modification, suggested by I. Fritz is to add a 1kΩ resistor in series with the diode [3]. This serves to provide clean chaotic signals with few sharp edges, artefacts or spikes.

The operational amplifier type is noncritical, although differing slew rates may affect the waveforms observed. The circuit was tested with 741, LF356, NE5534 and TL071. The TL071 can latch-up to the power rails when overdriven or used with rectangular input signals requiring the power switch to be reset, otherwise all versions displayed similar behaviour.

In addition to the introduction of the light emitting diode, there is a second unconventional component choice. In a typical twin-T configuration (see Figure 1), C1 and C2 should be of equal value and C3 should be half the capacitance of C1. In this circuit, C3 must be a tenth to a twentieth of the capacitance of C1.

The original circuit used an unspecified light-emitting diode as the nonlinear element. A variety of silicon and germanium signal diodes, which are often used to introduce nonlinearities in feedback systems, were tested [4, 5]. Chaotic signals were obtained in all cases. It was found that a higher on-voltage allowed the circuit to be easier to tune as a greater range of the control voltage potentiometer could be exploited. Blue light-emitting diodes were used, with a typical on-voltage of 3.4V.

The other advantage with using blue light-emitting diodes is the relatively shallow voltage/current curve, compared to other light-emitting and signal diodes. This slower change in resistance increases stability and ease of tuning the circuit. The nonlinear tuneable resistance of the light-emitting diode is the keystone of the circuit. Replacing the light-emitting diode with a resistor turns the circuit into a regular notch filter and chaotic phenomena cannot be obtained. Other studies of similar circuits have used a FET transistor in triode mode as the nonlinear element [6-8].

The circuit as shown in Figure 2 operates on a single sided DC power-supply. It will also operate on a bipolar supply. In this case R7, R8 and C7 should be omitted, R6 connected to ground and pin 4 of U1 should be connected to the negative power source. If an external control voltage source is required, it can be inserted through a 100kΩ resistor (R1) connected to the node of R2 and D1.

P1 sets the control voltage, as this voltage is increased, the circuit becomes more chaotic. P2 is the resonance or ‘Q’ control, generally this is set to a very low value, under 100Ω. P3 is the input attenuator this must be set up according to the amplitude of the input signal.

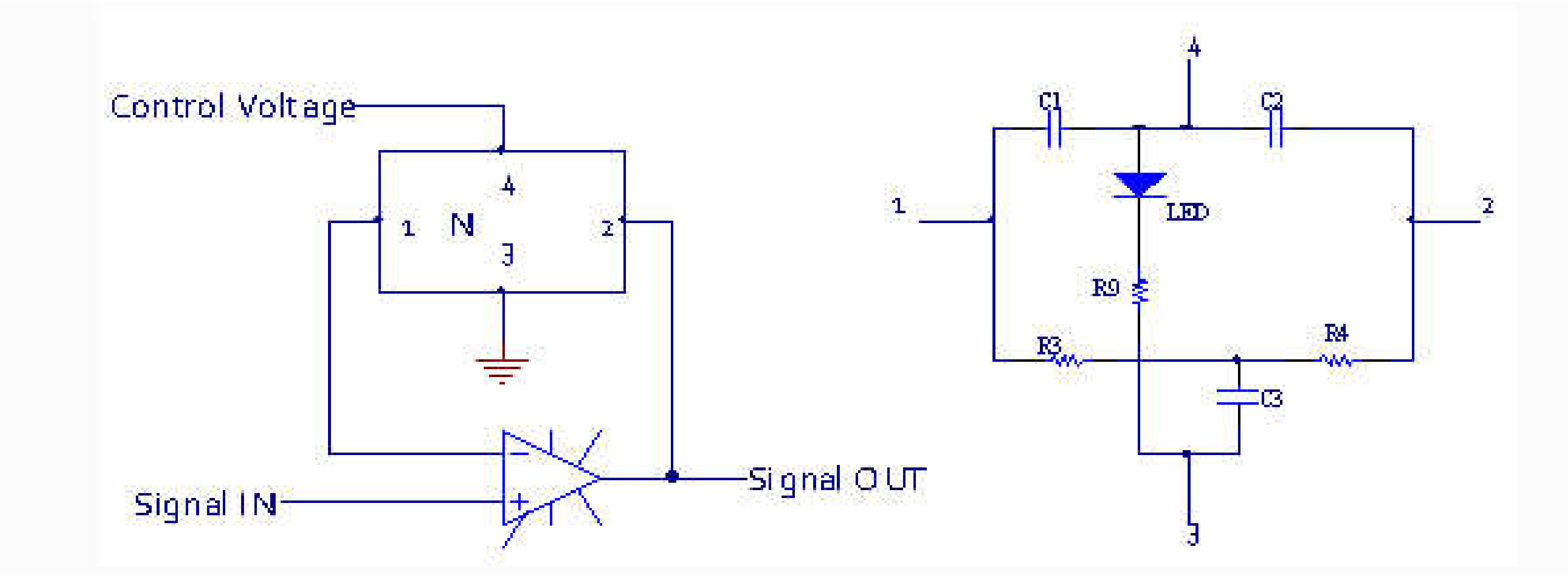

Figure 1: The Circuit Configuration and the Twin-T Network (N).

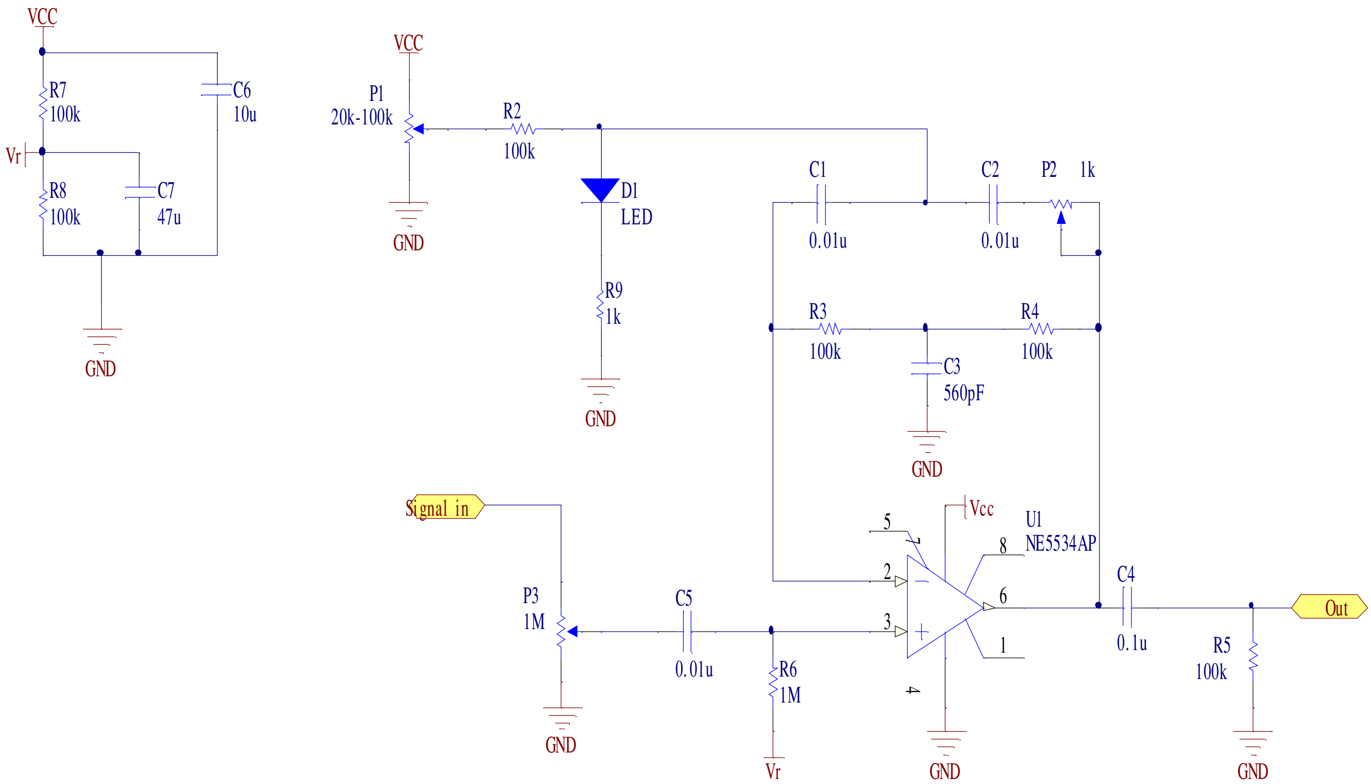

Figure 2: Q&D Chaos Schematic – Components used: *R1* – 100kΩ (optional, see text), *R2, R3, R4, R5, R7, R8* – 100kΩ, *R9* – 1kΩ, *R6* – 1MΩ, *C1, C2, C5* – 0.01uF, *C3* – 560pF (not critical, can substitute 470pF to 1000pF), *C4* – 0.1uF, *C6* - 10uF (decoupling, optional), *C7* – 47uF (decoupling, optional), *D1* – LED, *U1* – op-amp (741 or similar), *P1* – 20k-100kΩ linear potentiometer, *P2* - 1kΩ linear potentiometer, *P3* – 1MΩ linear potentiometer, *Power supply* – 9-15VDC.

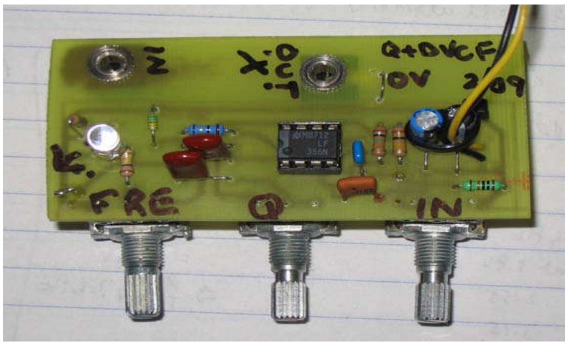

Figure 3: Physical Implementation of the Chaotic Circuit.

III. LABORATORY EXPERIMENTS

A printed circuit board layout was designed and three boards were etched and built (see Figure 3). Oscilloscope probes were attached to the anode of the light-emitting diode and to the output of the circuit, being the node of C4 and R5.

For these experiments, an Iwatsu SS-5702 oscilloscope (20MHz bandwidth) was used in X-Y mode and the images recorded with a Canon 3.2Mp digital camera. An interesting feature can be seen in the first and second sets of images, the only difference between the two sets is the frequency of the input signal. The lower frequency results in a much deeper well and a more symmetrical waveform at lower control voltage settings.

Further experiments were conducted using input signals with DC offset and signals with multiple breakpoints. Chaotic patterns of increased complexity were observed from the use of these different input signals. Connecting multiple diodes in series simply reduced the effect of the control voltage.

The driving input signal, used to obtain the following images, has a 9.5V peak to peak amplitude, is triangular and the frequency is set to 48Hz and subsequently 15Hz. The circuit will display chaotic behaviour when the amplitude of the input signal is as low as 0.5V p-p and as high as the op-amp is rated for. At low amplitudes the output signal will be proportionally as low. If the amplitude is too high the output signal will be clipped.

These experiments were performed using a 15V DC power supply. The input signal amplitudes and frequencies are noted with each set of images. The input attenuation is set to minimum and resonance set to maximum for each experiment.

Figures 4(a)-(f) show the output observed at stepped control voltage settings. Input signal: 9.5Vp-p triangle wave input at 48Hz.

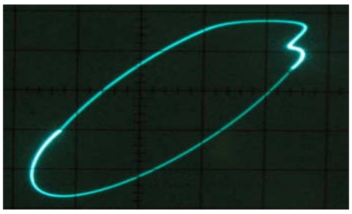

Figure 4(a): control voltage 0.7V

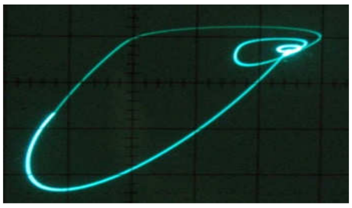

Figure 4(b): control voltage 1.9V

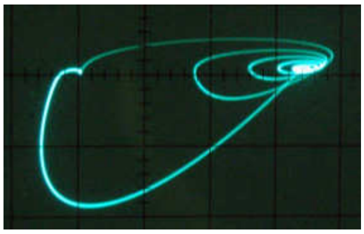

Figure 4(c): control voltage 4.6V

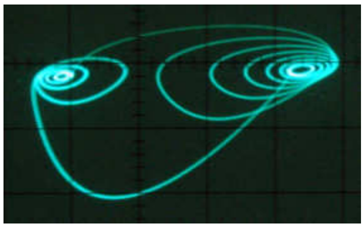

Figure 4(d): control voltage 6.3V

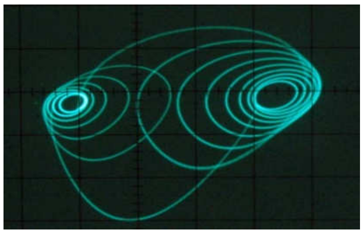

Figure 4(e): control voltage 12.6V

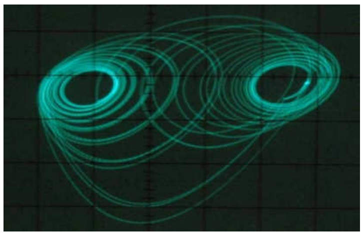

Figure 4(f): control voltage 14.0V

Figures 5(a)-(f) show the output observed at stepped control voltage settings. Input signal: 9.5Vp-p triangle wave input at 15Hz.

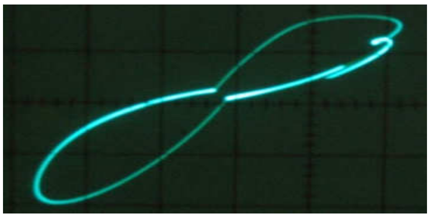

Figure 5(a): control voltage 1.8V

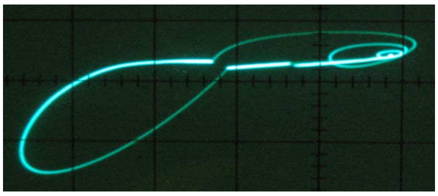

Figure 5(b): control voltage 2.5V

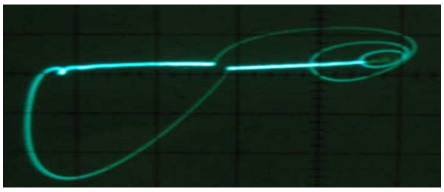

Figure 5(c): control voltage 3.2V

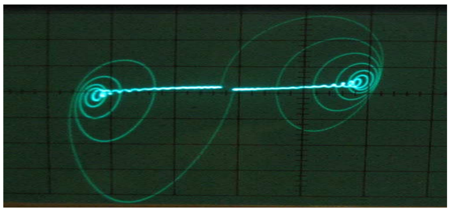

Figure 5(d): control voltage 5.5V

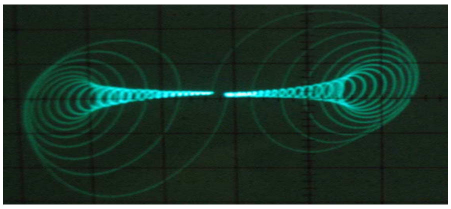

Figure 5(e): control voltage 10.1V

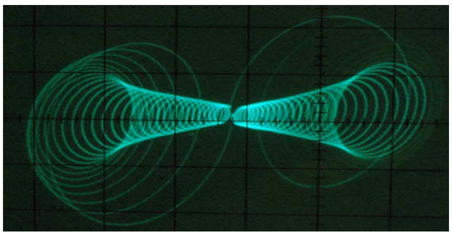

Figure 5(f): control voltage 15.0V

IV. Conclusion

In this paper, a driven chaotic circuit employing a single operational amplifier and twin-T sub-circuit was presented. It has a number of features such as adjustability of parameters, maintenance of good stability at low frequencies, no requirement for any special or expensive components and ease of assembly. Additionally, being a driven circuit, the desired format and behaviour of the chaotic output signal can be determined by selecting the appropriate wave type and frequency of the input signal.

The experiments showed the conditions required to obtain chaotic signals from the circuit and showed that a variety of different signals can be produced.

Although this circuit was originally designed to be used as a filter/distortion effect for guitarists and its chaotic behaviour was an unexpected by-product, research showed that it shares some similarities with circuits developed by Elwakil and Soliman for the purpose of studying chaotic signals [6]. There are two main points where this circuit differs from the modified twin-T oscillators presented by Elwakil and Soliman. It uses a cheap and common light emitting diode rather than a field-effect transistor as the nonlinear element. In addition, the circuit requires an input signal which allows a wide variety of unusual chaotic phenomena to be observed without the need to adjust the circuit or substitute components.

References

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