THE ACOUSTIC CHARACTERISATION OF CHUA'S CHAOS CIRCUIT

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Abstract

Chua's circuit has multiple applications - in politics, economics, telecommunications, technical physics, nanomaterial synthesis, biology - and is of interest thanks to the multitude of adjustment parameters in simulation processes. The paper presents the detailed acoustic analysis which represents a benchmark in relation to other technical systems, for example, DBD plasma.

Keywords: Chua's circuit, bifurcation, Matlab functions, sonogram, frequency, output

General overview of Chua's circuit

In the world of artistic entertainment, stage lighting based on the dynamic bifurcation of the spotlight is used, cf. *figure 1* (Murali K. and Lakshmanan M.,1990).

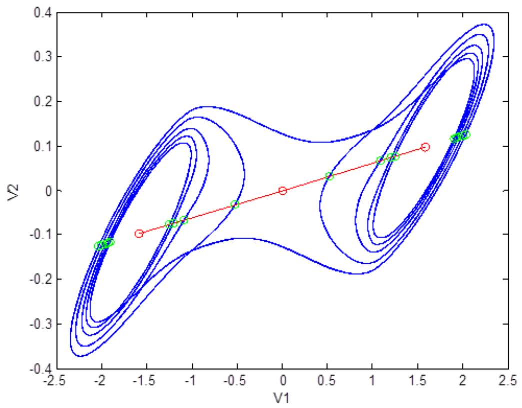

Figure 1 **Representation of bifurcation using the Chua circuit**

To achieve the scene effect (Leon O. Chua), 1992, the control electronic circuit includes the Chua circuit (Leon O. Chua; Kılıç Recai, 2010) consisting of five linear components - inductance L with internal resistance R, two capacitors C1 and C2, an external resistor R and a nonlinear component - an NR memristor or Cua diode as negative resistance, *figure 2*.

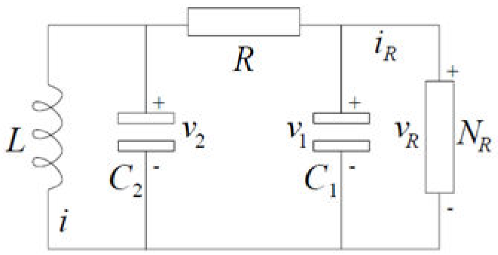

Figure 2 **General diagram of Chua's circuit**

MATERIAL AND METHOD

The dynamic electrical system with three degrees of freedom is described by the system of equations below:

$$\begin{cases} \dfrac{dx}{dt} = K\alpha[y - x - f(x)] \\ \dfrac{dy}{dt} = K\alpha(x - y + z) \\ \dfrac{dz}{dt} = k(-\beta y - \gamma)z \\ f(x) = bx + \dfrac{1}{2}(a-b)\cdot\{|x+1| - |x-1|\} \end{cases}$$

where γ, β, α, a, b, k are adjusting variables. The fine change in the parameters yields numerous forms of three-dimensional fractal structures that may be used to synthesize musical compositions.

For example, for a model, the control function takes the following form:

```
R = 1300;
R1 = 1200;
R2 = 3300;
r = 85;
C1 = 4.28e-9;
C2 = 69e-9;
L = .0085;
a = R1./R;
b = 1-R1./R2;
c = (C1.*(R1)^2)./L;
s = C1./C2;
p = r./R1;
F = @(t,y) [ a*(y(2,:)-y(1,:))-gbar(y(1,:),b); s*(-
a*(y(2,:)-y(1,:))+y(3,:)); -c*(y(2,:)+p*y(3,:)) ];
```

which can be generated up with the Matlab function ode45:

```
[ts, ys]  = ode45(F, [0 N], yo, odeset ('reltol', 1e-6,
'abstol', 1e-9));
```

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by setting the initial conditions:
N = 10000;
yo = [.1;.15;.05];
The following values result:
x1 = (1-b)/((a/(1+a*p))-b);
y1 = a*p*x1/(1+a*p);
z1 = -y1/p;
which can be analysed and represented graphically, Figure 1 sq.

RESULTS AND DISCUSSIONS

Experimental part. Work methodology

The acoustic signal of the **.avi** format video resulting from the the analysis of oscillograms was transferred to an .mp3 format file and then converted to **.wav** format with the following characteristics:

Length	00:01:07
Audio	
Bit rate	512kbps
Name	Chua film.wav
Item type	Wave Sound

that can be processed using the MATLAB function:
[y, f, nbits] = wavread('Chua film.wav'),
where: y – read values – column vector, [f nbits] = 32000 16, f – sample frequency.

Preliminary findings

Consecutive values in the y column vector y (single channel recording) were arranged in the three-dimensional vector tsd1 which, in the 3D representation, renders the spatial dispersion, *figure 3*.
tsd1 = [y (3:end,1) y (2:end-1,1) y(1:end-2,1)];
figure; plot3(tsd1(:,1), tsd1(:,2), tsd1(:,3), '.', 'markersize', 1);

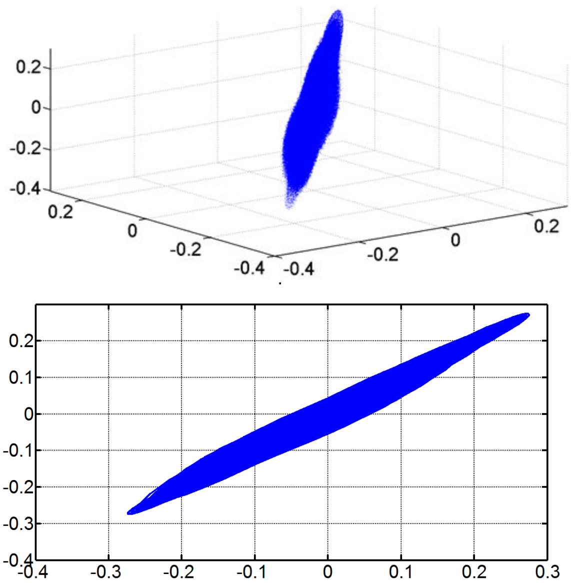

Figure 3 **Differences among consecutive values**

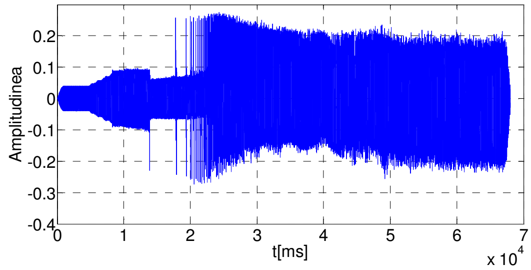

Figure 4 **Amplitude-time acoustic spectrum**

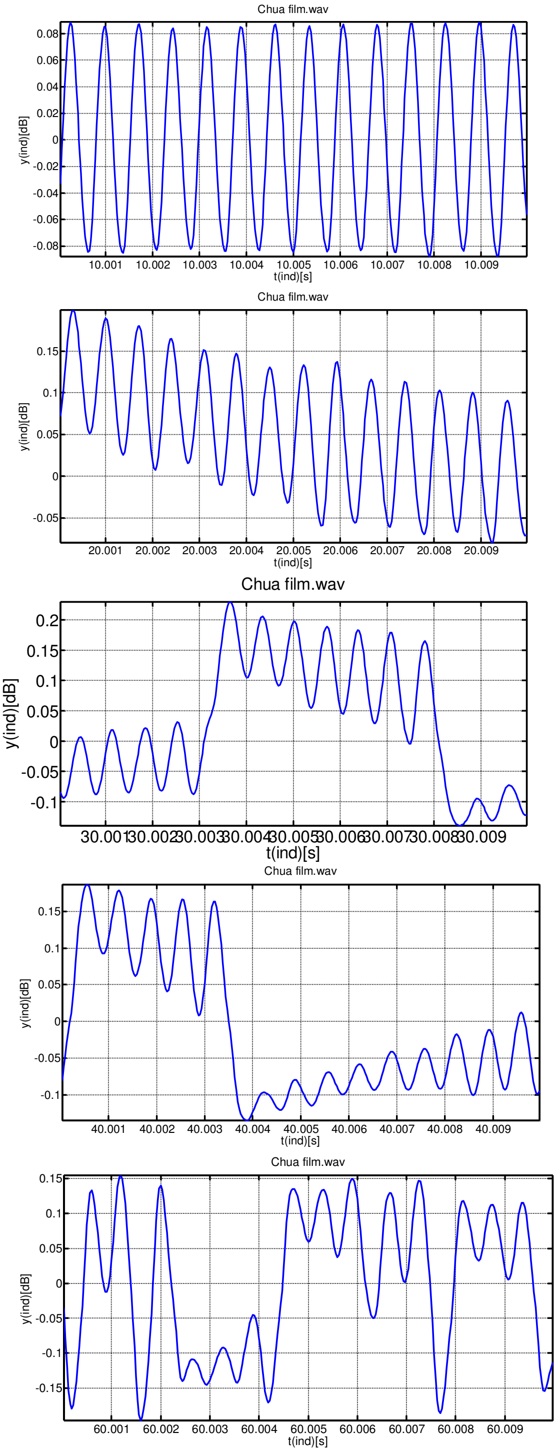

Figure 5 **Sequences in the acoustic spectrum for different durations**

The representations in *figure 2* indicate a spatial body with uneven distribution of consecutive values and an emerging state of chaos, correlated with stage lighting.

Acoustic analysis

During the recording:

t=size(y)./f, in seconds the change in acoustic signal amplitude was emphasised, *figure 4*.

By employing the Fourier transform as follows:

p = fft(y(:,1));

the diagram in *figure 6* is generated.

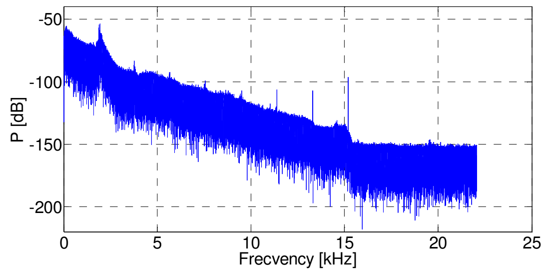

Figure 6 **Power-frequency spectrogram**

Using the sequence:

X = fft(y);
n = length(y);
P = X .* conj (X) / n;
w = f * (0:(n/2 - 1))/n;

results the magnitude of absolute values

y_fft = abs(fft(y));

from function

y_fft = y_fft(1:Nsamps/2);

presented in Figure 7 with the characteristic values:

rms_val =0.0871;
Et = 121.5017 W

and the amplitude cumulated by frequencies, *figure 8*.

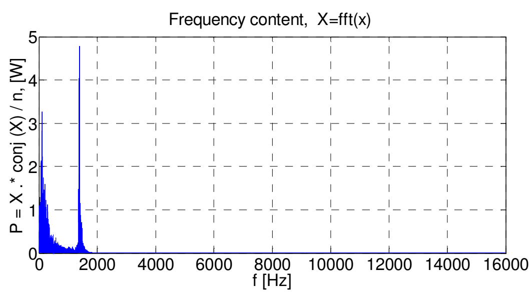

Figure 7 **Acoustic power - frequency**

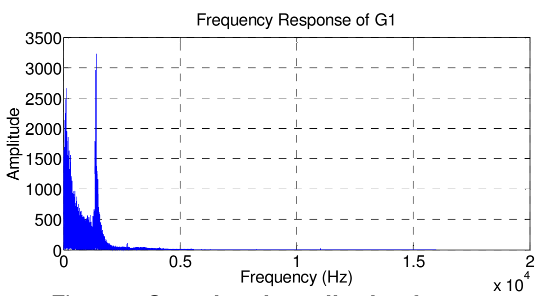

Figure 8 **Cumulated amplitude - frequency**

In a limited frequency field, the representation in *figure 9* is obtained.

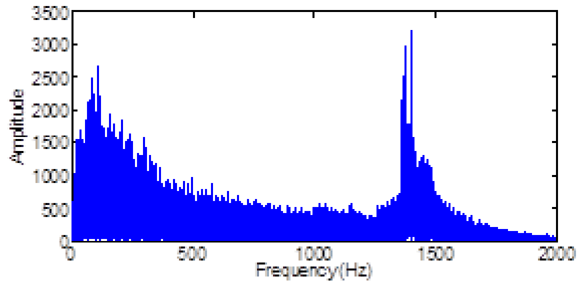

Figure 9 **Detail in *figure 6***

On the logarithmic scale the peak in maximum power is achieved at 1400 Hz frequency, *figure 10*.

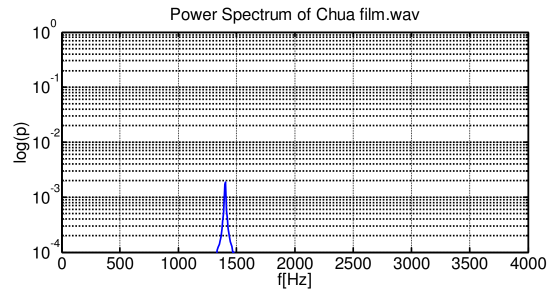

Figure 10 **Maximum range of acoustic power**

The spectrogram developed using the function:

specgram(y, 512, f);

indicates the uneven scattering at different frequencies in time, *figure 11*.

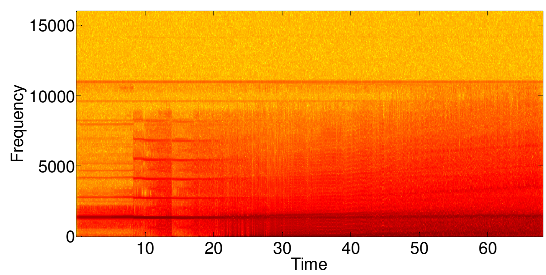

Figure 11 **Spectrogram**

h = spectrum.welch;

spectral estimator.

Hpsd = psd(h,y,'fs',f);
figure
plot(Hpsd)

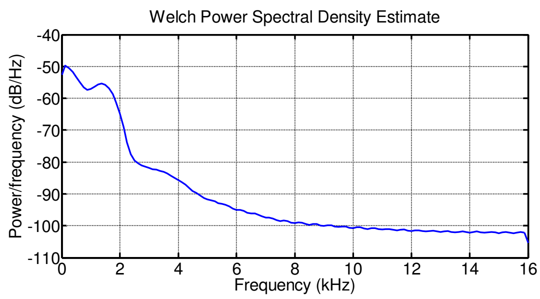

Figure 12 **Distribution of spectral power**

CONCLUSIONS

Compared to the existing state of technology - the electrotechnical representation of oscillograms - the paper presents a detailed acoustic analysis of the Chua dynamic circuit.

Data analysis yields the following results:

- change in amplitude over time, *figures 4*, *5* and *9*;
- acoustic power (W) in frequency dependency with two maximum values, *figure 7*, and total energy Et = 121.5017 W;
- broad frequency spectrum in the 0 - 2000 Hz range, cf. detail in *figure 9*;
- the maximum peak of acoustic power (dB) achieved at the 1400 Hz frequency, *figure 10*;
- unevenness of the spectrogram, *figure 11*;
- increase in specific acoustic power (noise) (dB/Hz) along with the increase in frequency.

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