Low-Cost Chaotic Correlation Optical Time Domain Reflectometer

Introduction and Background

An Optical time-domain reflectometer (OTDRs) is a device that can send pulses down fibre optic lines and is able to read the reflected light signature in order to act as a optical radar, alerting the user to a fault point, however, these can be expensive. By introducing chaos to existing OTDR technology chaotic correlation optical time-domain reflectometers (CCOTDR) may be used to reduce the cost of manufacturing and operation .

- Offer higher spatial resolution as the bandwidths of the waves generated are over 10GHz overcoming limitations of previous technology (COTDR)[1]
- The scaling of the time-delay with respect to the laser internal timescale and the sensitivity of the phase to the returning field create a means of inducing various dynamical scenarios leading to chaos

Aims and Objectives

- Understanding chaos- what it is what are its uses in the real world
- Understanding Semiconductor lasers- what they are, how they work, what's the most suitable design involving them for my project
- Understanding different methods to generate chaos using semiconductor laser-what are they, how do they work, pros and cons of each etc
- Demonstrate chaos OTDRs by using chaotic signal using semiconductor lasers subject to optical feedback

Method and Approach

After doing sufficient background research into the areas relating to the project, mainly using MATLAB to simulate chaotic signal created via a feedback loop and to calculate useful parameters such as Bandwidth as well as providing a platform to create graphs.

```
%%%%%%%parameters of the lasers and the filter%%%%%%%%%%%
b=3.2;                                  % linewidth enhancement factor
rc=5.36e11;                             % cavity decay rate
rn=7.53e9;                              % differential carrier relaxation rate
rp=1.91e10;                             % nonilinear carrier relaxation rate
rs=5.96e9;                              % spontaneous carrier relaxation
J=1.222;                                % normalized bias current above threshold
dv=1e6;                                 % full width at half0-maximum (FWHM) optical linewidth when the slave laser is free-runing

T_in=0;                                 % injection coefficient
f=0;                                    % detuing frequency beween the master laser and slave laser
R_fk1=0;                                % reflection coefficient of the ist feedback loop
R_fk2=[0;0.03;0.15;0.3];            % reflection coefficient of the 2nd feedback loop
h=1e-12;                                % step of the simulation
fk_tao1=2.4e-9;                         % time delay induced by the 1st feedback loop
fk_tao2=10e-10;                          % time delay induced by the 2nd feedback loop
t0=2000e-9;                            % span of the simulaiton
t=0:h:t0;                               % time
L=length(t);                            % total steps of the simulation
fL=floor(L*0.5+1);                       % start time of the figure
fH=floor(L*1);                          % end time of the figure
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

- Used scripts to quickly change variables such as Time delay and reflection coefficient off the first loop
- Checking impact of change on structure of graphs for spectrums and auto correlation
- Comparison of simulated bandwidth results

Figure 1.Example of Variables in a script used together multiple simulations of a single feedback loop each with varying pre-sets to be used.

```
clear all
tic
delay=220; %total delay time calculated

k1=1;% the first data files' number
k2=4;%the last data files' number
for k=k1:k2
  acc=zeros(delay+1,2);
name=sprintf('P%d_100.dat',k); %data file
data1=load(name); %load data
data=data1(:,2); %taken the second column data

N=length(data);%total number of samples
my=sum(data)/N;%Mean value


for tt=0:delay
 s1=0;
 t=0;
for m=1:(N-delay)
    s1=s1+(data(m)-my)*(data(m+tt)-my);
    t=t+(data(m)-my)^2;
end
acc(tt+1,2)=s1/t;%Auto-correlation coefficient data is save at the second column
end
acc(1:delay+1,1)=((0:delay)/10)'; %first colum is for delay time
save(sprintf('acc_P0%d.dat',k), 'acc', '-ascii')
figure(k+4)
plot(acc(:,1), acc(:,2))
xlabel('Time Shift (ns)')
ylabel('Auto correlation (a.u.)')

zoom on;grid on;
end
toc
```

Figure 2. A script used to generate auto correlation against time graph

```
%chaos bandwidth is defined as the frequency difference
%between dc and the frequency which contains 80% of the power

clear all
tic
fr_rang=30;            %Frequency range
k1=2;
k2=4;
kk=k2-k1+1;
bw=zeros(kk,2);         %data dimension
for k=k1:k2           % The serial number of the file
name1=sprintf('100rfspecfig%d.dat', k);    %files' name

data1=load(name1);%load the data
L=length(data1(:,2));
data2=10.^(data1(:,2)/10);      %Converted signal from logarithmic scale to linear scale
tot=sum(data2(3:L))       %Total power
s1=0.8*tot                 %80% of the total power
freq=0;
s=0;
for t=3:L
    s=s+data2(t);            %Accumulation of power
    if s<s1
        freq=fr_rang/(L-1)*t;
    end

end
bw(k-k1+1,1)=k;
bw(k-k1+1,2)=freq;
end

save bw2ndTD10neg4.dat bw -ascii
toc
```

Figure 3, MATLAB script to calculate the chaos bandwidth of each case in one go

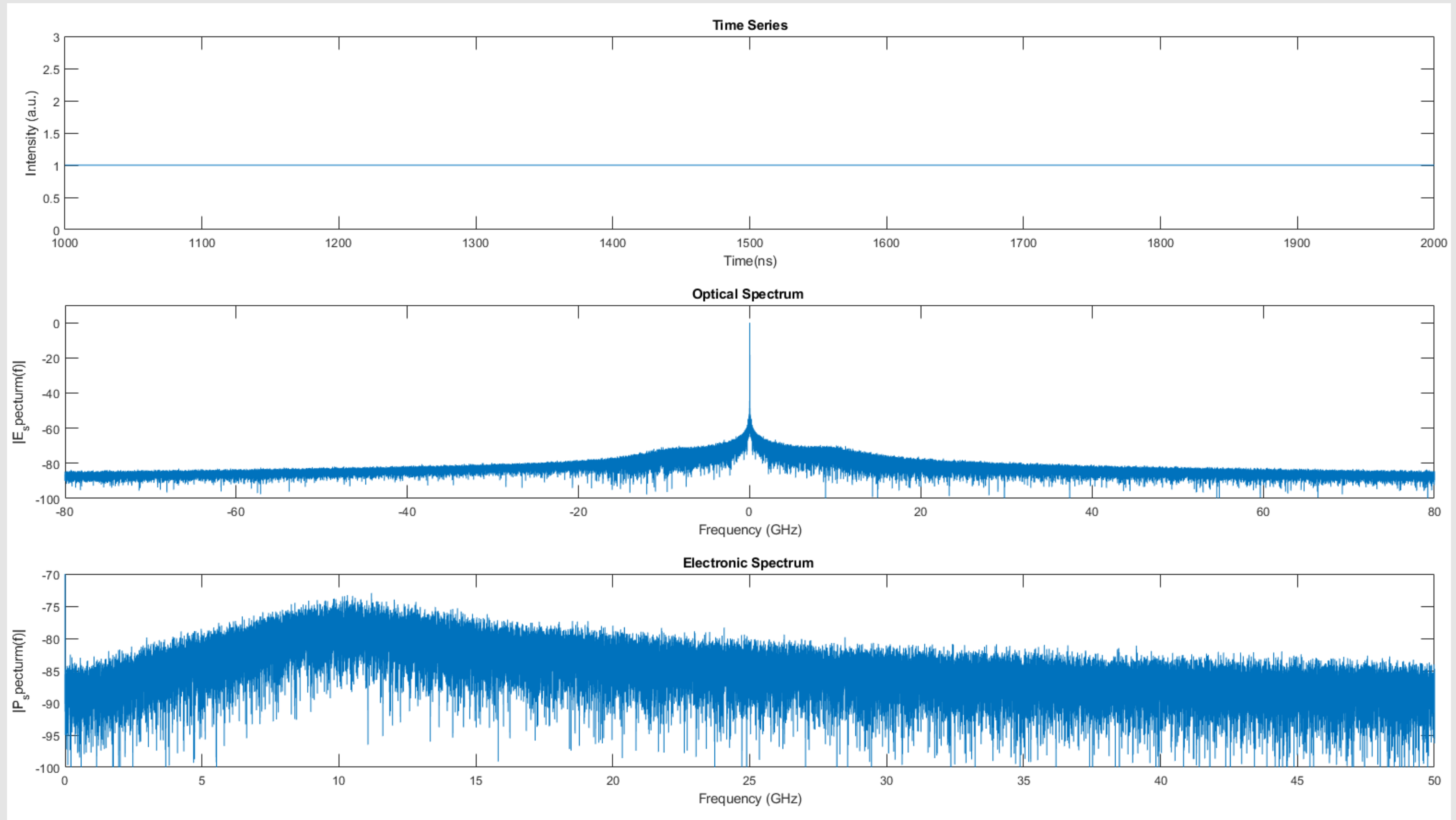

Figure 4, results from case where the reflection coefficient is 0time delay of 10 nano seconds so no chaotic signal is shown

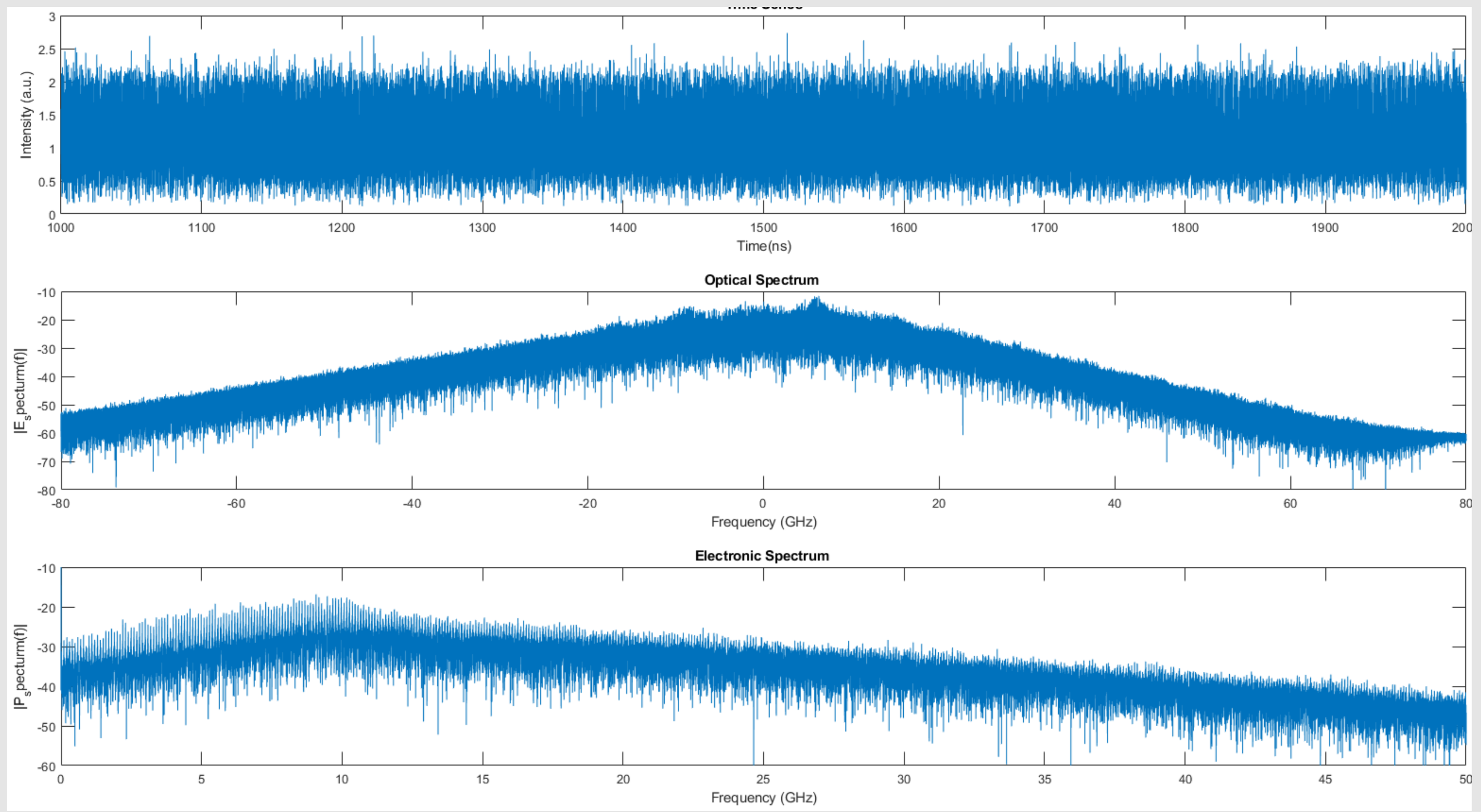

Figure 5, results from case where the reflection coefficient is 0.03 and time delay of 10 nano seconds

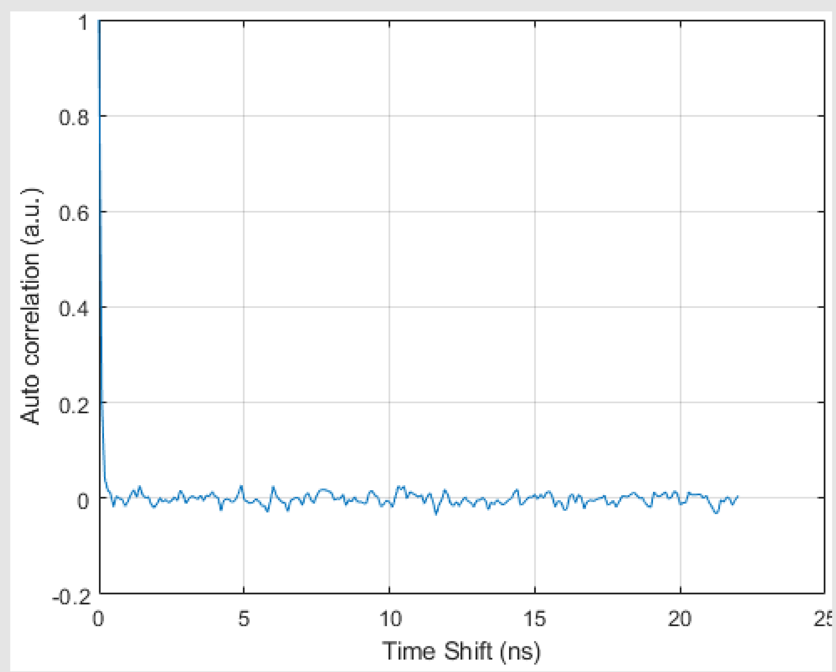

Figure 7 Auto correlation over time for feedback loop with no reflection coefficient

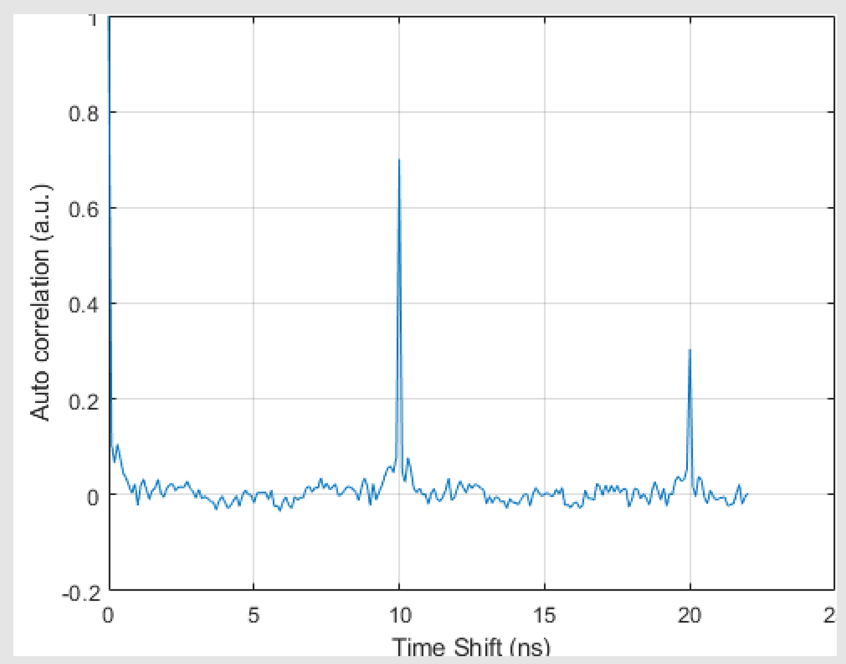

Figure 8 Auto correlation over time for feedback loop with a reflection coefficient of 0.3,with peaks occuing at 10ns intervals the time delay in the loop

[1] "chaos theory and its applications in our real life" barishal university journal part 1, 5(1&2): 123-140 (2018) issn 2411-247x 123 hena rani biswas*,1, md. Maruf hasan2 and shujit kumar bala1 [2]Kane, D. M. & Shore, K. A. Unlocking Dynamical Diversity: Optical Feedback Effects on Semiconductor Lasers (Wiley, 2005)

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