Three Level System

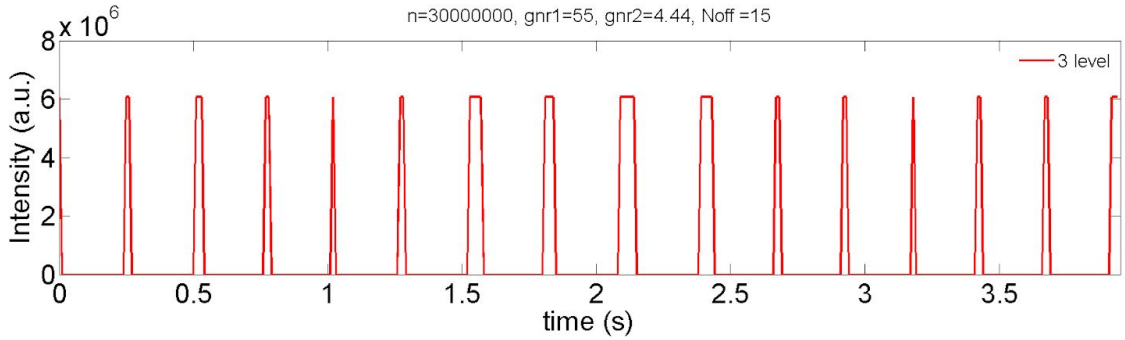
In this system three levels were defined- level 1, 2, 3. Level-1 is the ground state, level-2 is the excited state and level-3 is the trap state. p is the pumping rate from ground state to the excited state. gnr1 is the rate of transition from the excited state to the trap state. gnr2 is the rate of transition from the trap state to the ground state. gsp is the rate of transition from the excited state to the ground state. LT=1/gsp is the lifetime for the carrier.

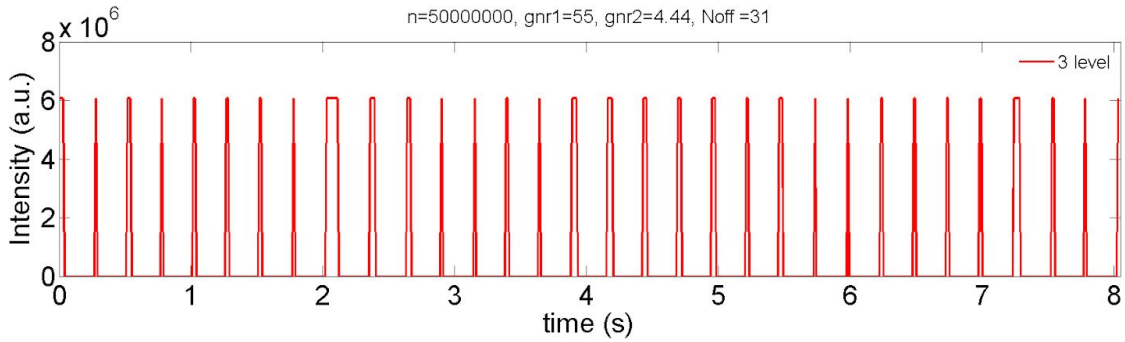
Model-1

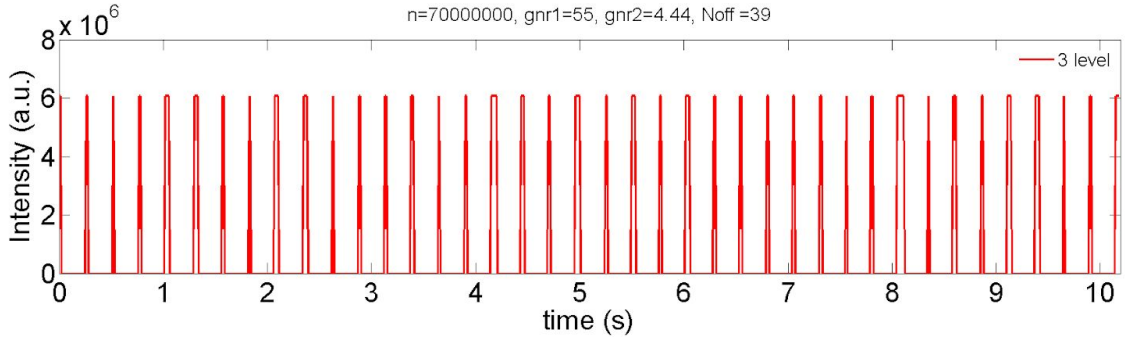
In this model LT follows the random exponential distribution with a given mean value. Whenever the transition takes place from excited state to the ground state directly, the increment in time is equal to the Lifetime of the carrier. In case of transition of carrier from the excited state to the ground state via the trap state, the increment in time is given by 1/gnr1 + 1/gnr2. A carrier when in excited state can make a transition either to the ground state or the trap state, this is decided by generating a random number between 0 & 1 and comparing it with gnr1/(gsp+gnr1). If the random number is less than this ratio then it goes in the trap state otherwise in the ground state. After running the code for certain number of iterations, binning is done the intensity array keeping bin size =10 milliseconds.

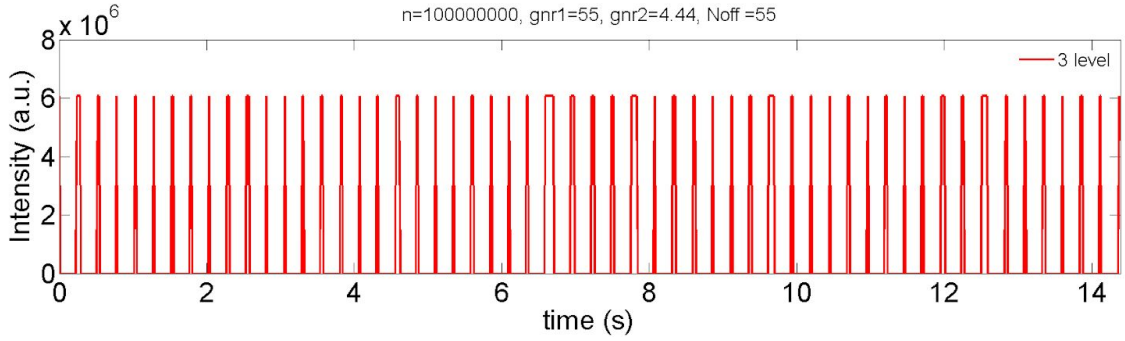
Results:

Case 1: gnr1=55, gnr2=4.4

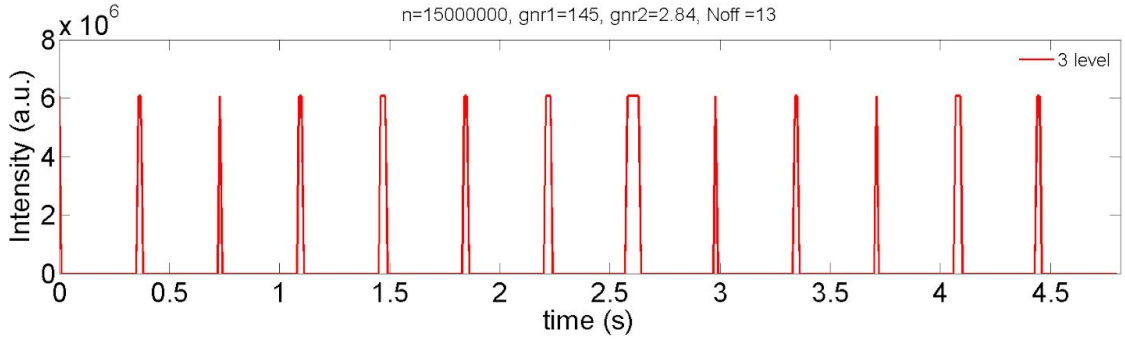


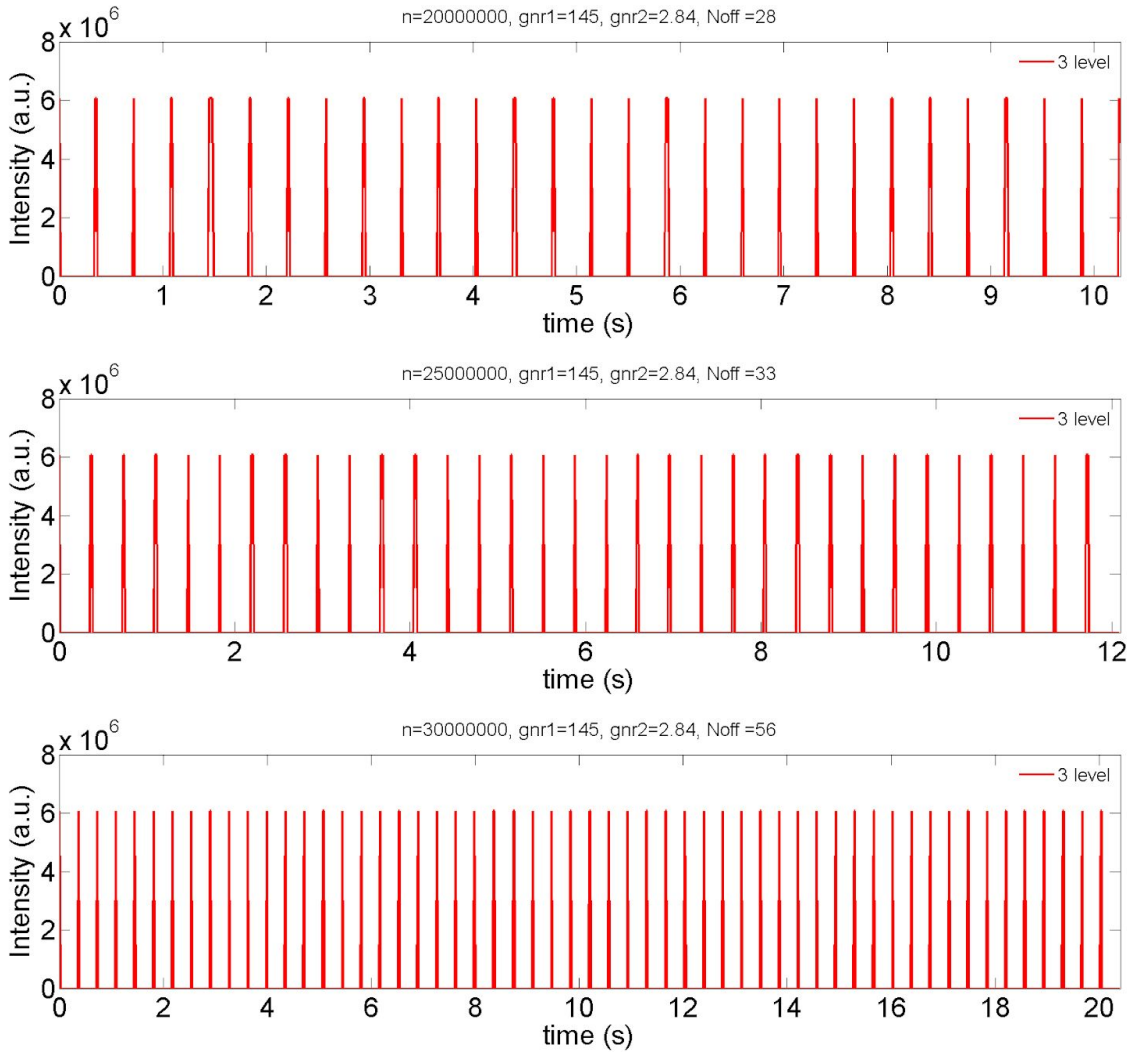






Case 2: gnr1=145, gnr2=2.84




n=20000000, gnr1=145, gnr2=2.84, Noff =28
x 10^6
Intensity (a.u.)
time (s)
3 level
n=25000000, gnr1=145, gnr2=2.84, Noff =33
x 10^6
Intensity (a.u.)
time (s)
3 level
n=30000000, gnr1=145, gnr2=2.84, Noff =56
x 10^6
Intensity (a.u.)
time (s)
3 level

Bin size= 10 msec

Code:

```
clear;
clc;
close all;
tic
n=1; %current iteration
n1=25000000;%total number of iterations
p=10^7; %pumping rate
LT=10e-9;  %initialised here, follows exponential distribution
T=exprnd(LT,1,n1);
gnr1=145; %rate of going from excited to trap state
gnr2=2.84;  %rate of going from trap to ground state
bin_size=10^-2;  %size of each bin

t(1)=0; % stores time at which intensity is measured
intensity(1)=0; %intensity at a particular time
i=2; %index for time array
j=2; %index for intensity array
k=1; %index for choose array
q=1; %index for gsp1 array(array of gsp)
c=1; %index for iterating over time while binning
count=0; %number of time it goes in trap state
while n<=n1
    gsp1=1./T(n); %random number generated for gsp from exponential
distribution
   %{
       while gsp<10^7  % put limit to value of gsp
        gsp=exprnd(10^8);
       end
        %}

S3=sqrt(p.^2-2*p*gnr1-2*p*gnr2+2*p*gsp1+gnr1.^2-2*gnr1*gnr2+2*gnr1*gs
p1+gnr2.^2-2*gnr2*gsp1+gsp1.^2)/2;
    S2=p/2 +S3 +gsp1/2 +gnr1/2 +gnr2/2;
    S1=p/2 -S3 +gsp1/2 +gnr1/2 +gnr2/2;
    A1=(p*gnr1)/(p*gnr1+p*gnr2+gnr1*gnr2+gnr2*gsp1);
    A2=(S1/(2*S3))*A1;
```

```
    A3=-(S2/(2*S3))*A1;
    gsp2(q)=gsp1; %store gsp in gsp1
    choose(k)=rand();  %random number from 0 to 1 for choosing which
state it goes
    if choose(k)<(gnr1/(gsp1+gnr1)) % case when carrier goes into
trap state
        intensity(j)=0;
        j=j+1;
        t(i)=t(i-1)+ 1/gnr1 +1/gnr2; %rise in time
        i=i+1;
        count=count+1;
    else  %case when it goes to ground state directly
        t(i)=t(i-1)+1/gsp1; %rise in time

intensity(j)=(gsp1^2/(gsp1+gnr1))*((gnr2*A1/gnr1)+((gnr2-S2)/gnr1)*A2
*exp(-S2/gsp1) + ((gnr2-S1)/gnr1)*A3*exp(-S1/gsp1));  % function for
intensity
        i=i+1; %increment in time index
        j=j+1;  %increment in intensity index
    end

    k=k+1;
    n=n+1;
    q=q+1;
end
plot(t, intensity,'o')
figure()
n=fix(max(t)/bin_size); %number of bins formed
i1=zeros(n,1); %array initialized with zero to store intensity after
binning
for m=1:n %iterating over each bin
 cprev=c;
   while t(c)<m*bin_size
      i1(m)=i1(m)+intensity(c);
      c=c+1;
   end
   diff=c-cprev;
 i1(m)=i1(m)/diff; %average of intensity is stored after binning
```

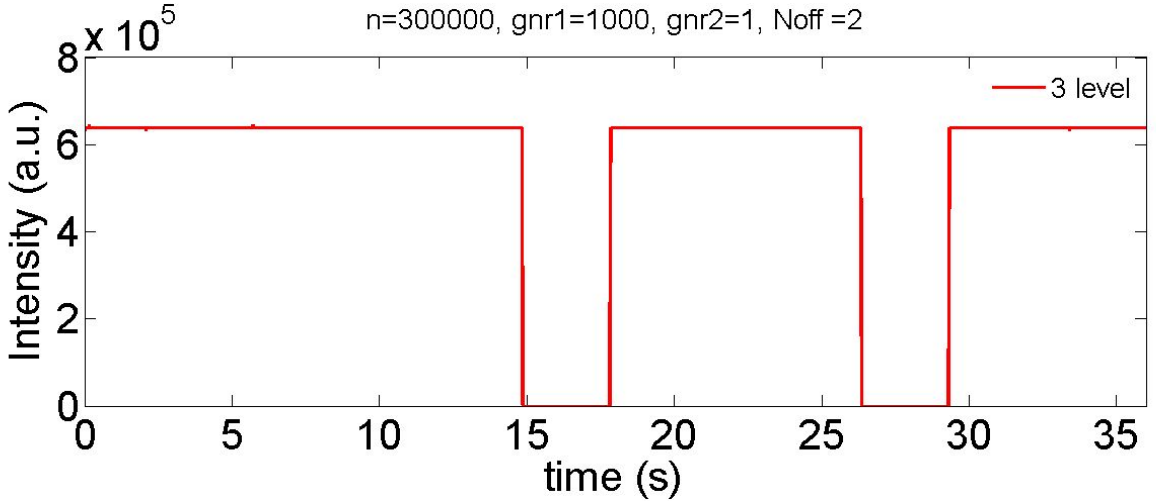
```
end
i1(isnan(i1)) =0;%replace all NaN to 0 in i1 array
t1 = 0:bin_size:(n-1)*bin_size;

c = [[0,0,0];[0.7,0.7,0.7];[1,0,0];[0,1,0];[0,0,1]];
line_style = {'-','--','-.','-'};
plot(t1,i1,'LineWidth',2,'Color',
[c(3,:)],'LineStyle',line_style{1});
xlim([0, max(t)]);

h_legend = legend('3 level','Location','NorthEast');
title(['n=',num2str(n1),', gnr1=',num2str(gnr1),',
gnr2=',num2str(gnr2), ', Noff =',num2str(count)],'fontsize',16)
set(h_legend,'fontsize',16, 'box', 'off');
xlabel('time (s)','fontsize',24);
ylabel('Intensity (a.u.)','fontsize',24);
set(gca, 'Fontsize',24);

figname_png = ['Intensity and time for 3 level system8.png'];
figname = ['Intensity and time for 3 level system8'];
width = 15;
height = 4;
set(gcf, 'PaperPositionMode', 'manual');
set(gcf, 'PaperSize', [width height]);
set(gcf, 'PaperPosition', [0 0 width height]);
set(gca,'position',[0.1 0.19 .85 .7]);% specify these as the fraction
of the total.. between 0 and 1

print('-dpng','-r125',figname_png);
toc
```

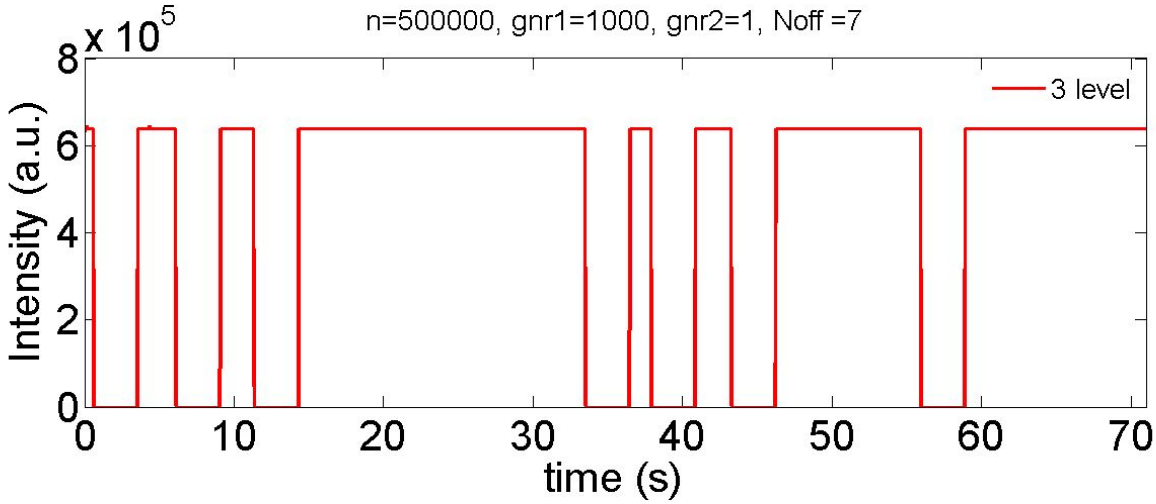
Model-2

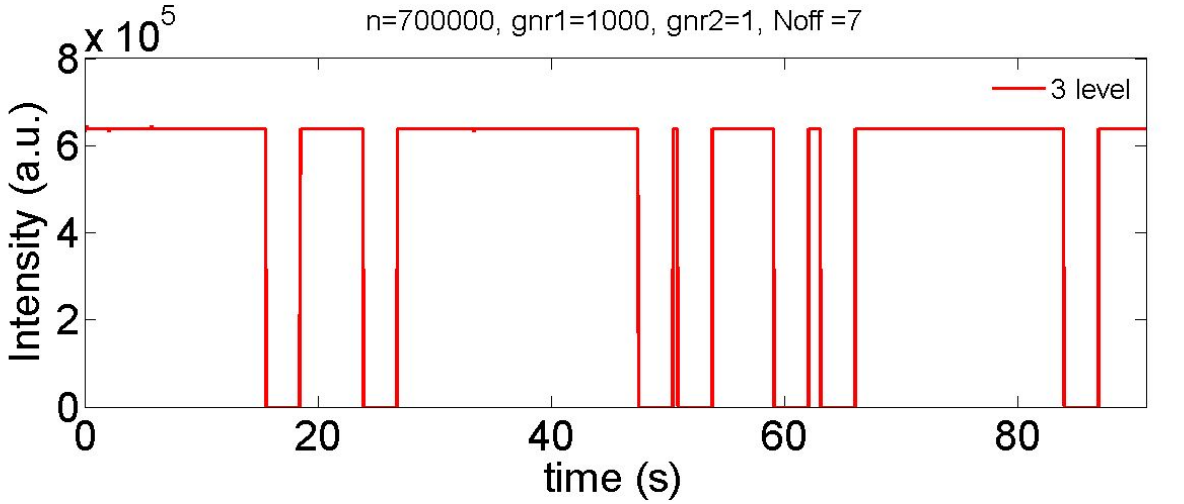
This model also incorporates the effect of pumping rate. The carrier waits in the ground state until next pulse arrives and excitation takes place.

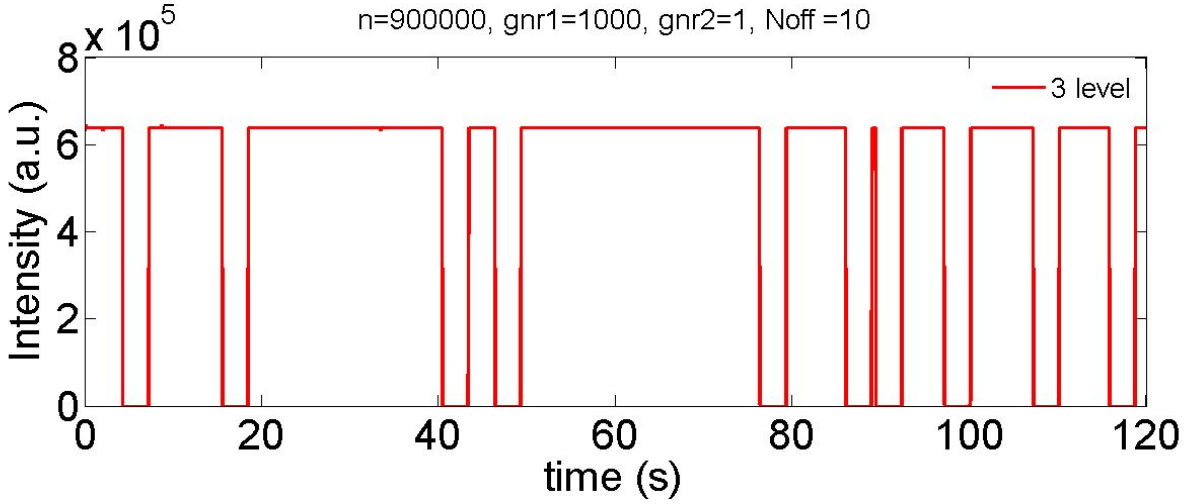
Results:

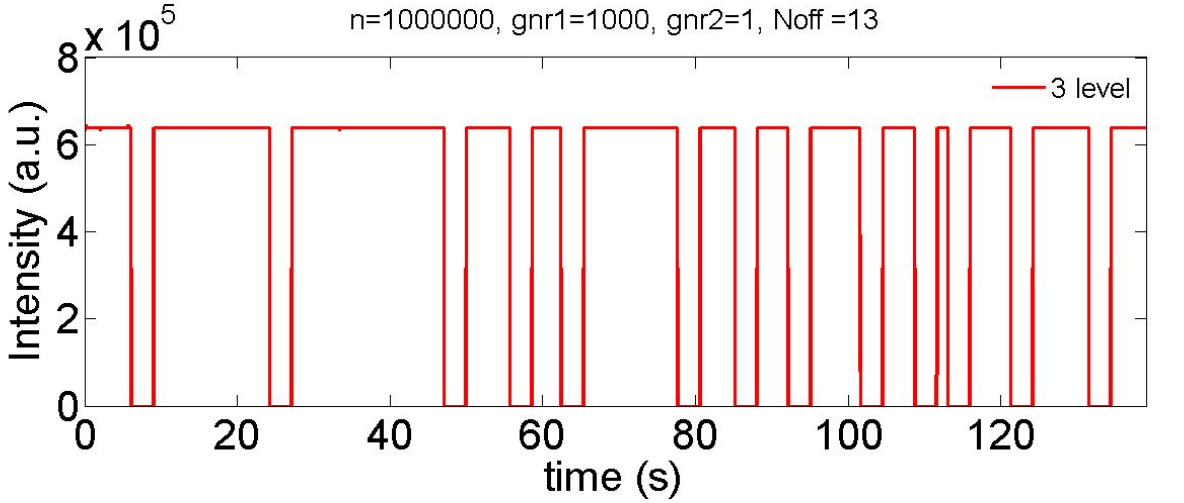
gnr1=1000, gnr2=1, p=10000, lifetime = 10 nsec

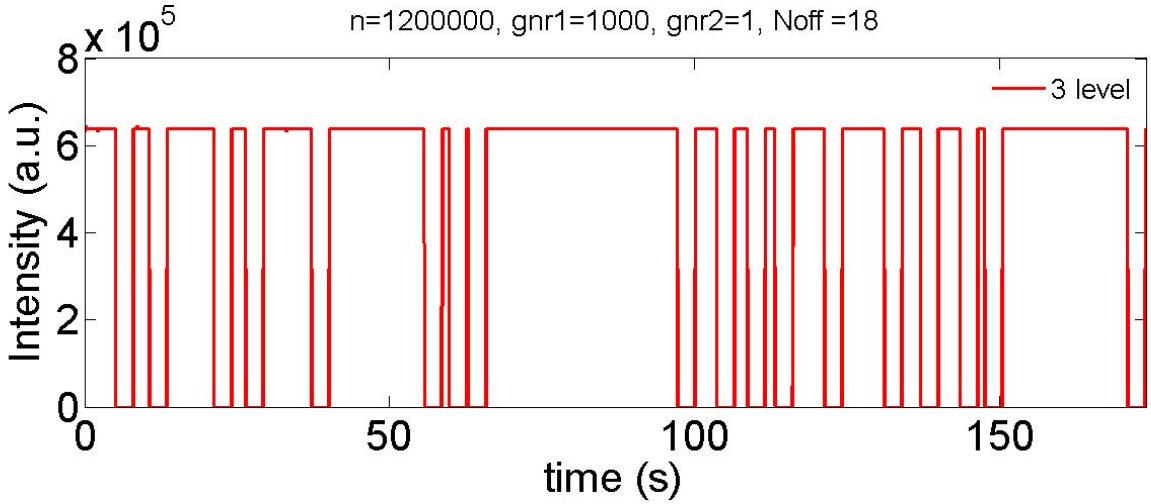


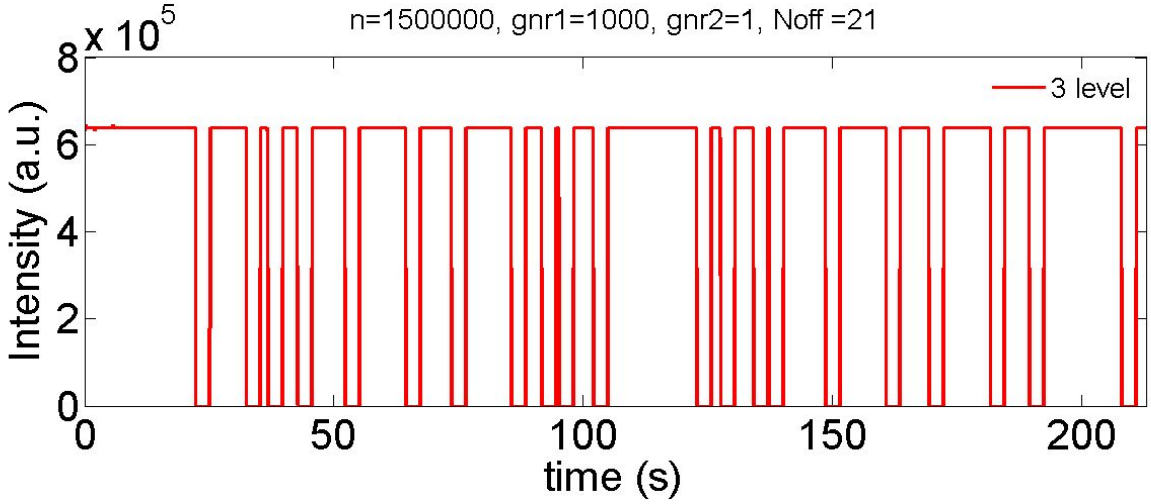


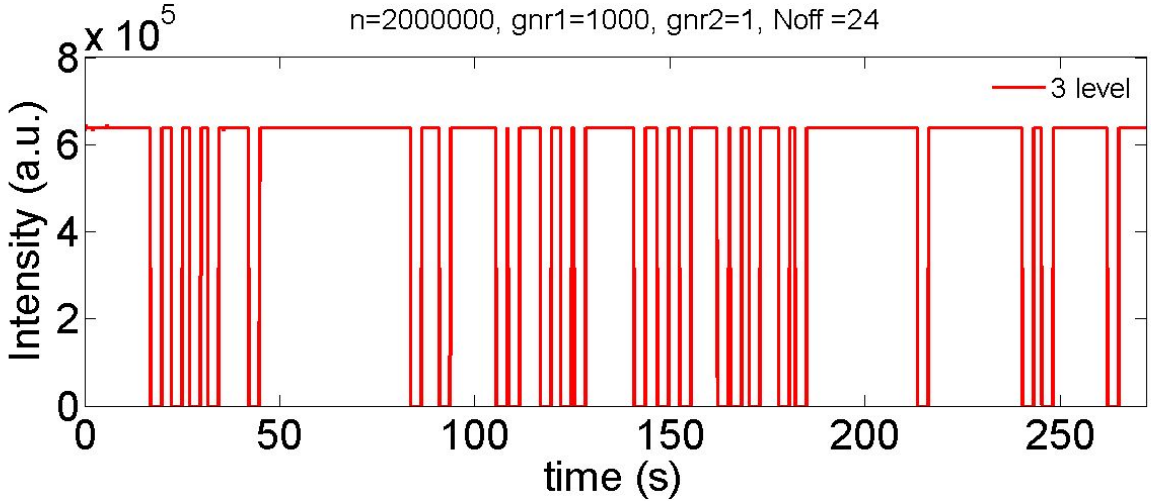

n=700000, gnr1=1000, gnr2=1, Noff =7
x 10^5
Intensity (a.u.)
time (s)
3 level


n=900000, gnr1=1000, gnr2=1, Noff =10
x 10^5
Intensity (a.u.)
time (s)
3 level


n=1000000, gnr1=1000, gnr2=1, Noff =13
x 10^5
Intensity (a.u.)
time (s)
3 level


n=1200000, gnr1=1000, gnr2=1, Noff =18
x 10^5
Intensity (a.u.)
time (s)
3 level
0
2
4
6
8
0
50
100
150


n=1500000, gnr1=1000, gnr2=1, Noff =21
x 10^5
Intensity (a.u.)
time (s)
3 level
0
2
4
6
8
0
50
100
150
200


n=2000000, gnr1=1000, gnr2=1, Noff =24
x 10^5
Intensity (a.u.)
time (s)
3 level
0
2
4
6
8
0
50
100
150
200
250

Code:

```
clear;
clc;
close all;
tic
n=1; %current iteration
n1=1000000;%total number of iterations
p=10000; %pumping rate
LT=10e-9;  %initialised here, follows exponential distribution
T=exprnd(LT,1,n1);
gnr1=1000; %rate of going from excited to trap state
gnr2=1;  %rate of going from trap to ground state
bin_size=10^-2;  %size of each bin

t(1)=0; % stores time at which intensity is measured
intensity(1)=0; %intensity at a particular time
i=2; %index for time array
j=2; %index for intensity array
k=1; %index for choose array
q=1; %index for gsp1 array(array of gsp)
c=1; %index for iterating over time while binning
count=0; %number of time it goes in trap state
while n<=n1
    gsp1=1./T(n); %random number generated for gsp from exponential
distribution
   %{
       while gsp<10^7  % put limit to value of gsp
        gsp=exprnd(10^8);
       end
        %}

S3=sqrt(p.^2-2*p*gnr1-2*p*gnr2+2*p*gsp1+gnr1.^2-2*gnr1*gnr2+2*gnr1*gs
p1+gnr2.^2-2*gnr2*gsp1+gsp1.^2)/2;
    S2=p/2 +S3 +gsp1/2 +gnr1/2 +gnr2/2;
    S1=p/2 -S3 +gsp1/2 +gnr1/2 +gnr2/2;
    A1=(p*gnr1)/(p*gnr1+p*gnr2+gnr1*gnr2+gnr2*gsp1);
    A2=(S1/(2*S3))*A1;
    A3=-(S2/(2*S3))*A1;
```

```
    gsp2(q)=gsp1; %store gsp in gsp1
    choose(k)=rand();  %random number from 0 to 1 for choosing which
state it goes
    if choose(k)<(gnr1/(gsp1+gnr1)) % case when carrier goes into
trap state
        intensity(j)=0;
        j=j+1;
        t(i)=t(i-1)+ 1/gnr1 +1/gnr2; %rise in time
        count=count+1;
        h=fix((1/gnr1 +1/gnr2)/(1/p));
        t(i)=t(i)+(h+1)*(1/p) - 1/gnr1 +1/gnr2;
        i=i+1;
    else  %case when it goes to ground state directly
        t(i)=t(i-1)+1/gsp1; %rise in time

intensity(j)=(gsp1^2/(gsp1+gnr1))*((gnr2*A1/gnr1)+((gnr2-S2)/gnr1)*A2
*exp(-S2/gsp1) + ((gnr2-S1)/gnr1)*A3*exp(-S1/gsp1));  % function for
intensity
        g=fix((1/gsp1)/(1/p));
        t(i)=t(i)+(g+1)*(1/p) - 1/gsp1;
        i=i+1; %increment in time index
        j=j+1;  %increment in intensity index

    end


    k=k+1;
    n=n+1;
    q=q+1;
end
plot(t, intensity,'o')
figure()
n=fix(max(t)/bin_size); %number of bins formed
binranges=0:bin_size:max(t); %stores the various bins
[bincounts, ind]=histc(t,binranges); % bincounts stores the number of
indices of t array in each bin
%len=length(bincounts);
st=1;
```

```
for y=1:n %binning method
   %ran=st:bincounts(y);
   i1(y)= sum(intensity(st:bincounts(y)+st));
   st=bincounts(y)+1;
end

%{
i1=zeros(n,1); %array initialized with zero to store intensity after
binning
for m=1:n %iterating over each bin
 cprev=c;
   while t(c)<m*bin_size
      i1(m)=i1(m)+intensity(c);
      c=c+1;
   end
   diff=c-cprev;
  %average of intensity is stored after binning
end
%}
i1(isnan(i1)) =0;%replace all NaN to 0 in i1 array
t1 = 0:bin_size:(n-1)*bin_size;

c = [[0,0,0];[0.7,0.7,0.7];[1,0,0];[0,1,0];[0,0,1]];
line_style = {'-','--','-.','-'};
    plot(t1,i1,'LineWidth',2,'Color',
[c(3,:)],'LineStyle',line_style{1});
    xlim([0, max(t)]);

    h_legend = legend('3 level','Location','NorthEast');
    title(['n=',num2str(n1),', gnr1=',num2str(gnr1),',
gnr2=',num2str(gnr2), ', Noff =',num2str(count)],'fontsize',16)
    set(h_legend,'fontsize',16, 'box', 'off');
    xlabel('time (s)','fontsize',24);
    ylabel('Intensity (a.u.)','fontsize',24);
    set(gca, 'Fontsize',24);

    figname_png = ['Intensity and time for 3 level system(histc
```

```
binning)5.png'];
    figname = ['Intensity and time for 3 level system(histc
binning)5'];
    width = 25;
    height = 10;
    set(gcf, 'PaperPositionMode', 'manual');
    set(gcf, 'PaperSize', [width height]);
    set(gcf, 'PaperPosition', [0 0 width height]);
    set(gca,'position',[0.1 0.19 .85 .7]);% specify these as the
fraction of the total.. between 0 and 1

    print('-dpng','-r125',figname_png);
toc
```