

Matlab^r and Simulink Use in Response Analysis of Automobile Suspension System in Design

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Abstract In designing automobile suspension, response analysis is an important tool. In this paper, the response analysis of the auto suspension to various road conditions is studied using MATLAB tools and SIMULINK. The suspension system was modeled as a combination of dashpot and spring system in parallel attached to the auto body. Laplace transforms were used in obtaining transfer functions from the ordinary differential equations which described the system. The system, a second order open loop with a unity feed back 'type 1' system was subjected to different inputs and the response was studied using Matlab inbuilt commands and SIMULINK. The system was observed to be stable to frequency input using the Nyquist diagram. Very fast settling time was observed for the responses. It was observed that it was much easier to design compensators for the system using the Matlab commands. Using MATLAB root locus plot, the system could be re-designed by choosing new locus points and the new gains and damping ratios could be obtained. With the rlocfind command, the gains in the graphics window and the damping ratio could be found as well. With this a better design of the system could be obtained by compensating the system. This brings a dynamism into the design system.

Keywords Response, Auto Suspension, Transfer Function, Design

1. Introduction

Automobile suspension system containing the damper and spring system serve the purpose of absorbing shocks due to road incongruities thereby making our ride pleasant. Other method of studying the system include the Finite Element Method(FEM). However, this is very cumbersome and weeks of programming and are needed to fully study system of response of system to various inputs. With the advent of control engineering software like Matlab, the process of design has been greatly simplified and stimulating.

This work studies the use of Matlab and Simulink in studying auto body's transient response to various types of road incongruities and how this is important in Engineering Education.

2. Methodology

The automobile suspension system was modeled as a combination of dashpot and spring in parallel attached to the auto body. Mathematical equations for motion of the system was formulated and the transfer functions derived using Laplace transforms. The transfer function was analysed to obtain its various parameters. The transfer function was

then subjected to various probable road inputs. These are, step input, impulse, ramp and sinusoidal.

2.1. Mathematical Derivation of system Equations

Figure 1 shows a simplified schematic diagram of the auto suspension system. During motion, the vertical displacement of the tires put the auto suspension system into motion. The motion X_i at point P is the road input to the system while the vertical motion of the auto-body, X_o is the output. This vertical motion of the auto-body is what the driver and the occupants feel.

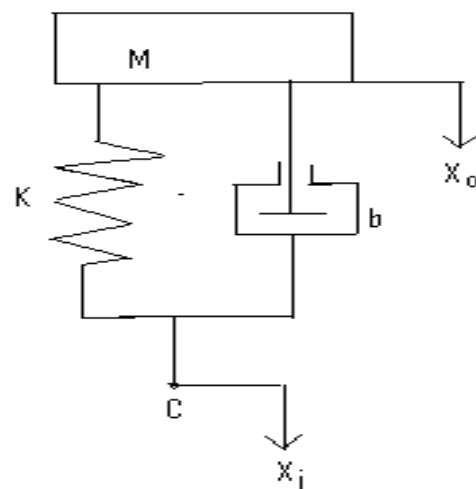


Figure 1. Simplified auto-suspension system

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Published online at <http://journal.sapub.org/ijtte>

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The equation for the system motion is

$$m\ddot{x}_0 + b\dot{x}_0 + kx_0 = b\dot{x}_i + kx_i \quad (1)$$

Taking Laplace transforms of (1) and inputting zero initial conditions gives

$$m[s^2 X_0(s) - sx_0(0) - \dot{x}_0(0)] + b[sX_0(s) - x_0(0)] + kX_0(s) = b[sX_i(s) - x_i(0)] + kX_i(s) \quad (2)$$

$$X_0(s)[ms^2 + bs + k] = X_i(s)[bs + k]$$

$$\frac{X_0(s)}{X_i(s)} = \frac{bs + k}{ms^2 + bs + k} = \text{overall transfer function}$$

This overall transfer function describes a linear second order 'type 1' unity feedback system which can be represented in block diagrams as shown in Fig.2.

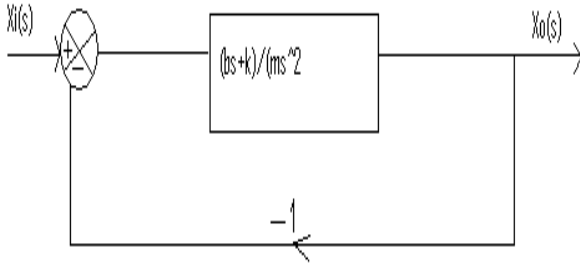


Figure 2. Block diagram of the auto-suspension system

The forward transfer function is $(bs+k)/(ms^2)$ while the feedback is unity.

Values used for the simulation were; $m = 1000\text{Kg}$; $b = 20\text{KN-s/m}$; $k = 500\text{KN/m}^2$.

2.2. Using Matlab in Response Analysis

Various Matlab commands were used in response analyses of the auto-suspension system. Inputs were step input, impulse, ramp and sinusoidal.

2.2.1. Unit Step Response

For unit step response i.e. $R(s) = 1/s$ at $t > 0$, the use of the command `step(num,den)` gave the desired result.

2.2.2. Unit Impulse Response

The impulse command has $R(s) = 1$;

Using `impz(num,den)`, the graph was plotted.

2.2.3. Unit Ramp Response

Ramp response is represented by $R(s) = 1/s^2$

Since Matlab has no direct ramp command, the step command can be used

The step command of $G(s)/s$ is obtained where $G(s)$ is the overall transfer function for the system. Alternatively, the command `lsim(num,den,r,t)` OR `lsim(A,B,C,D,u,t)` could be used

Where r and u are the input time functions. The command

goes thus:

```
num=[0 20 500];
den=[1 20 500];
t=0:0.005:0.4;
r=t;
y=lsim(num,den,r,t);plot(t,r,'-',t,y,'o')
```

Fig.5 shows the result of the unit ramp response.

2.2.4. The response of the steady-state of the system to sinusoidal Input

The response of the system to sinusoidal input was studied using the Bode plot. The Nyquist and Nichols plots gave same results. Use was made of the command `Bode(num,den)` to get the Bode diagram.

2.3. Using SIMULINK^R in Response Analysis

In using Simulink, it was important to obtain the poles first using the rootlocus plot. This plot gives the open loop zero and open loop poles for the system. These values are input into the transfer function property forms.

2.3.1. Root locus plot of $(20s+100)/(s^2+20s+500)$

The rootlocus plot(Fig.3) was obtained by using the following commands:

```
num=[0 20 500];
den=[1 20 500];
rlocus(num,den)
```

The root locus plot showed the open loop zero and open loop poles for the system.

These could be observed to tally with the complex conjugate open loop poles (roots of $s^2+20s+500$) which were obtained by using the following procedure.

```
b=[1 20 500];
roots(b)
ans =
-10.0000 +20.0000i
-10.0000 -20.0000i
>> a=[20 500];
>> roots(a)
ans = -25
```

Values obtained were:

Open loop zero: $s = -25$

Open loop poles: $s = -10 \pm j20$

Poles $(-10+20j$ and $-10-20j)$ were input into the transfer function property form. The simulink flow diagram was set up(Fig.4) and the simulation started. Results of different input signals were obtained.

3. Results and Discussion

3.1. Results

Results of the system responses to different inputs using Matlab commands are presented in Figs. 5 -11. The response to step input(Fig.5) showed a *rise_time* of 0.043s, *peak_time* = 0.11s, a *maximum_overshoot* of 0.3305, *settling_time* of

0.34s, final value of 1 and a peak amplitude of 1.34. The response to an impulse input (Fig.6) showed a peak amplitude of 20.4 at time of 0.011s and a settling time of 0.383s. The response to a unit ramp input (Fig.7) showed the a good response output. Figs. 8 and 11 showed good response to sinusoidal inputs while Figs. 9 and 10 showed very sharp initial rise time for sudden steep inputs.

Fig. 12 -14 shows the frequency response plots using Bode, Nyquist and Nichols diagrams. Delay margins to frequency response was as small as 0.057s. Closed loop was stable. The values obtained showed the system stability to different sinusoidal inputs.

The system responses to different inputs using SIMULINK are presented in Figs. 15-22. Fig.23 presents the use of the signal generator in building a signal. The results followed the same pattern obtained using Matlab commands.

3.2. Discussion

3.2.1. Response to various inputs

Response to the various inputs (Figs.5-11) showed a fast rise time and settling time. This showed that there is good compensator in the system.

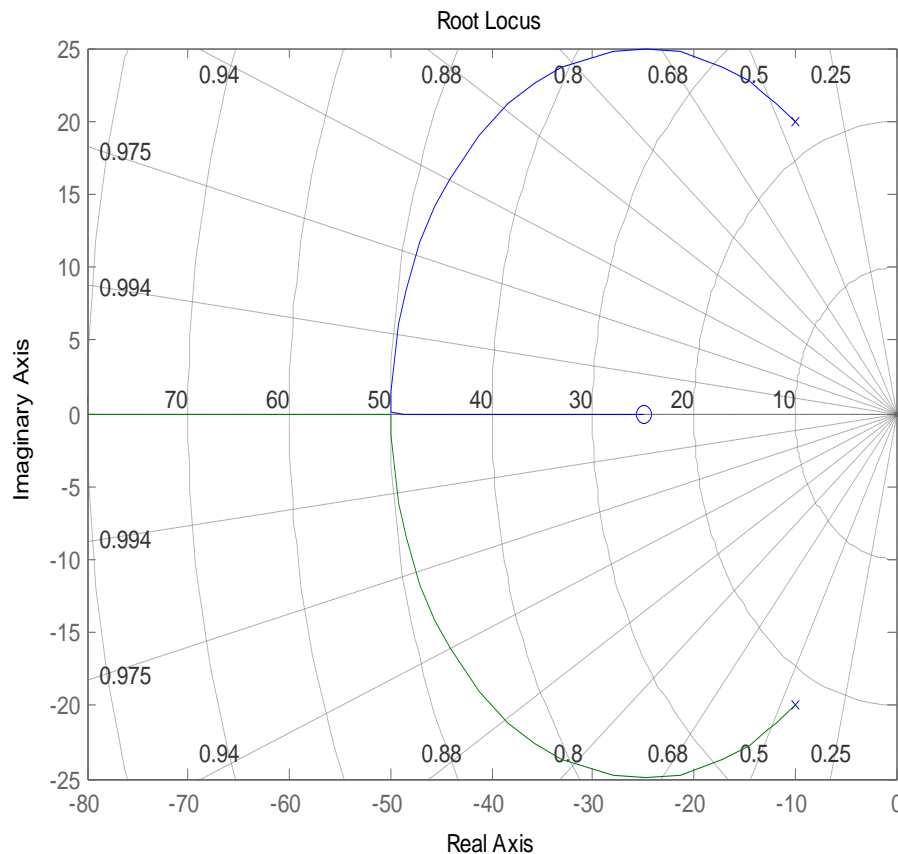


Figure 3. Root locus plot of $(20s+500)/(s^2+20s+500)$

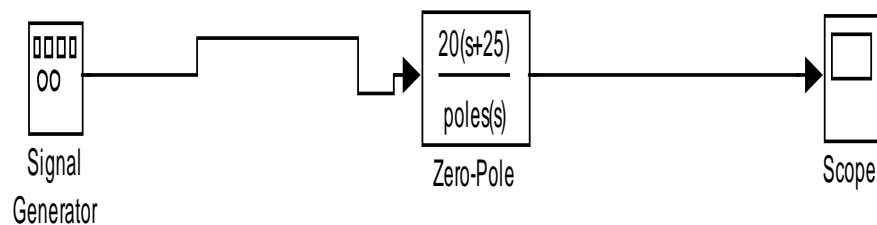


Figure 4. Simulink flow diagram with a signal generator, the transfer function and the scope

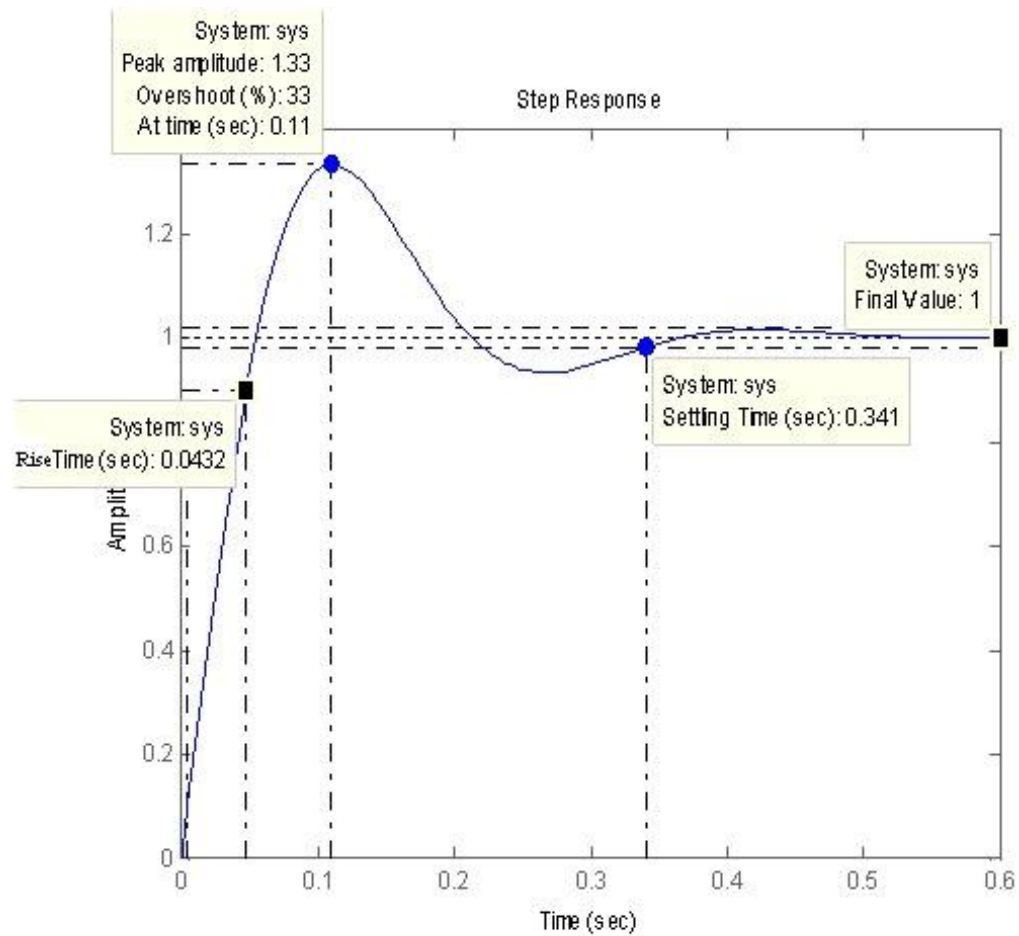


Figure 5. Response curve to a step input

Rise_time = 0.043s; Peak_time = 0.11s; max_overshoot = 0.3305;
settling_time = 0.34s; Final Value = 1; Peak Amplitude = 1.34

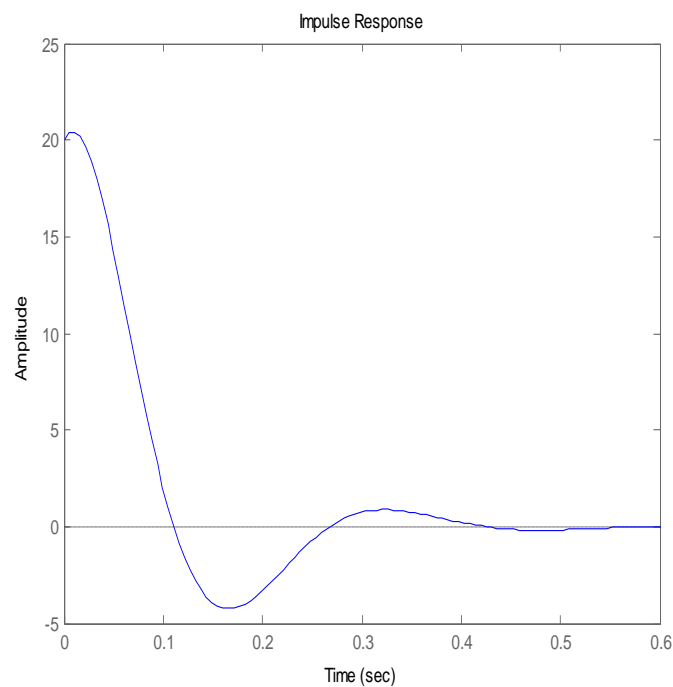


Figure 6. Response to impulse input

3.2.2. Response of the steady-state to sinusoidal input

The response of the steady-state of the system to sinusoidal input was studied here. The frequency of the input signal was varied and the response to this input by the system at steady state was studied here. The Bode, Nichols and Nyquist diagrams reveal the same response to sinusoidal inputs with varying frequencies. The system studied showed

stability. The Nyquist plot is a polar plot of the frequency response. We could observe the same values obtained in the Bode plot are replicated here: Peak Response: Peak gain=3.82Db at frequency of 18.9rad/sec

Minimum stability Margins:Phase margin=103deg. At a frequency of 31.6 rad/sec with a delay margin of 0.057sec showed that the closed loop is stable.

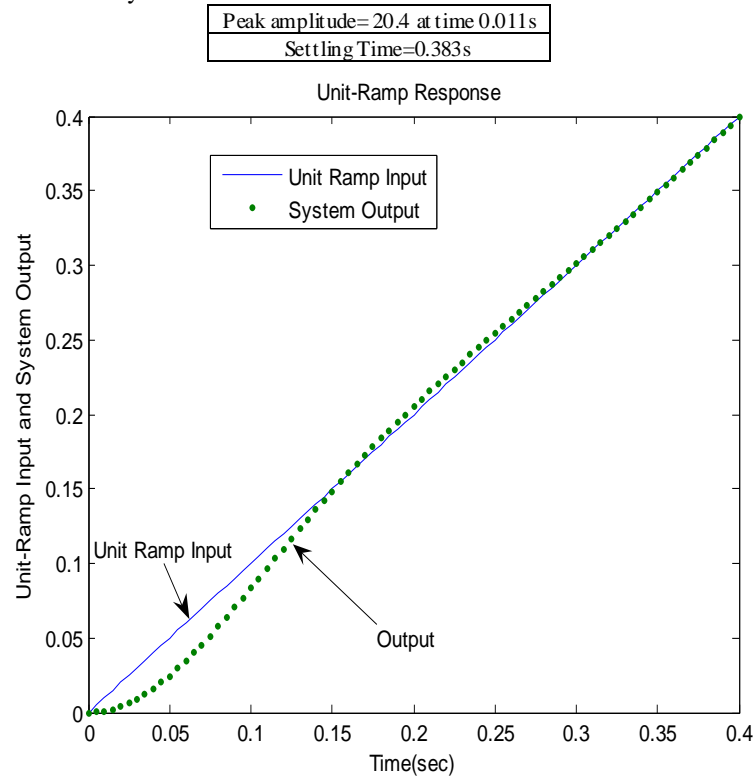


Figure 7. Response to a unit ramp input

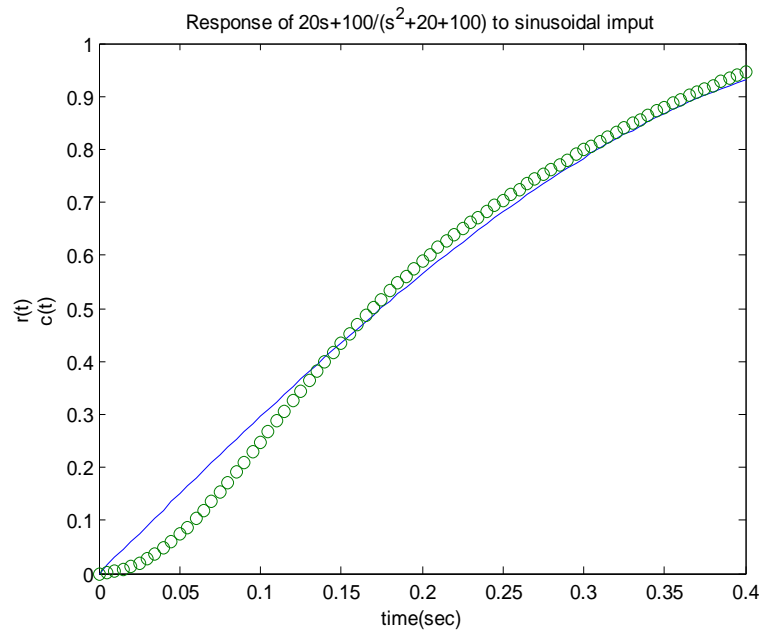


Figure 8. Response to a sinusoidal input $\sin 3t$

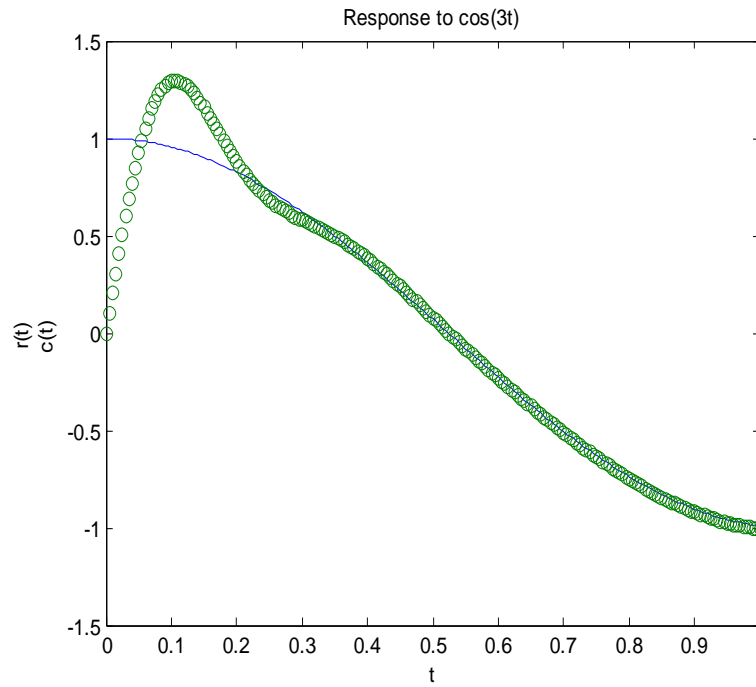


Figure 9. Response to $\cos 3t$ input

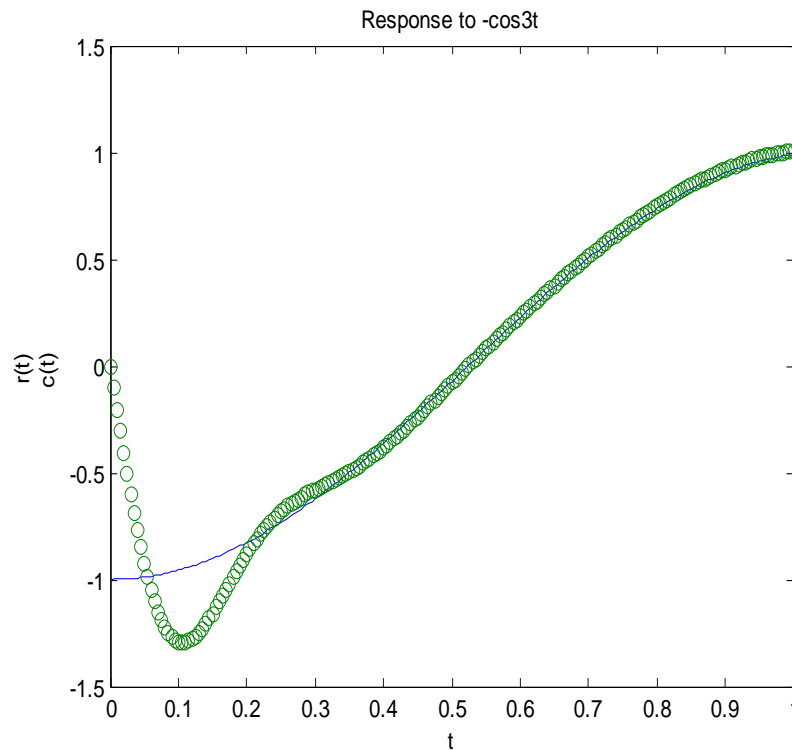


Figure 10. Response to $-\cos 3t$ input

3.2.3. Modeling, simulating and Designing With Matlab

In the root locus plot (Fig.3), the system could be re-designed by choosing new locus points and the new gains and damping ratios could be obtained. With the `rocfind` command, the gains in the graphics window and the damping ratio could be found as well. With this a better design of the

system could be obtained by compensating the system. This brings a dynamism into the design system.

3.2.4. Modeling, simulating and Designing With Simulink

With Simulink, the user has to obtain the poles first using the rootlocus plot. This plot gives the open loop zero and

open loop poles for the system. These values are then input into the transfer function property forms. Thus, it is important when using Simulink to work with both the rootlocus plot and the Simulink transfer forms. It is the

input into the transfer functions that brings out the responses of the system to various input signals(Figs.15-22). Input signals can be obtained using the signal buider (Fig.23).

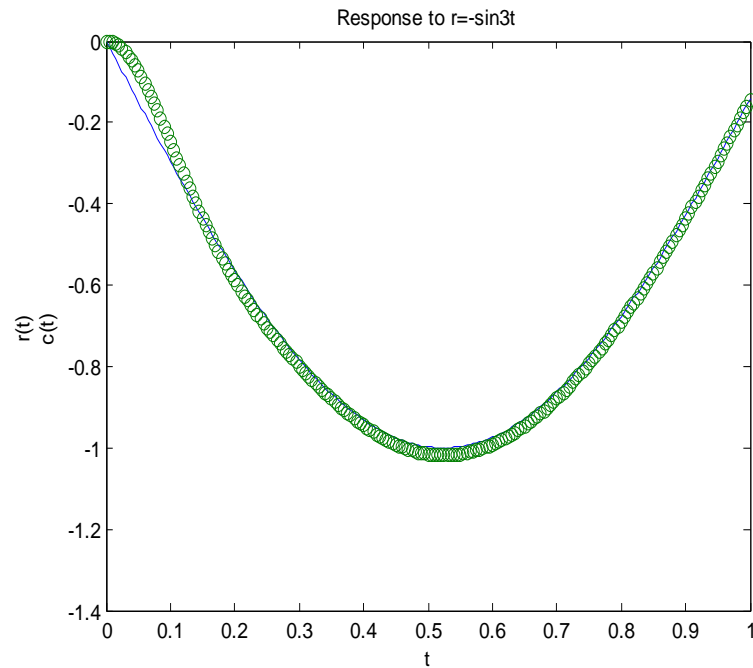


Figure 11. Response to $-\sin 3t$ input

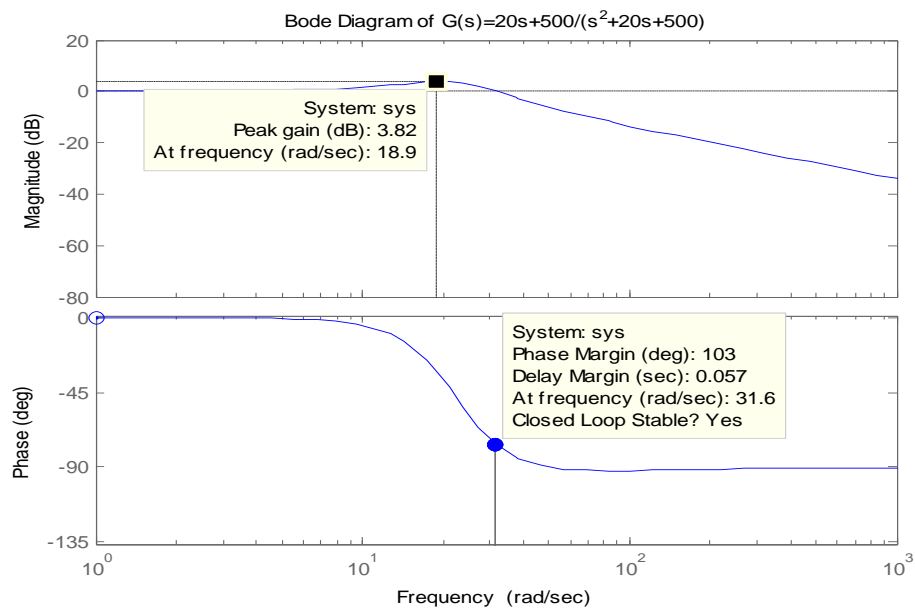


Figure 12. Bode diagram for $(20s+500)/(s^2+20s+500)$

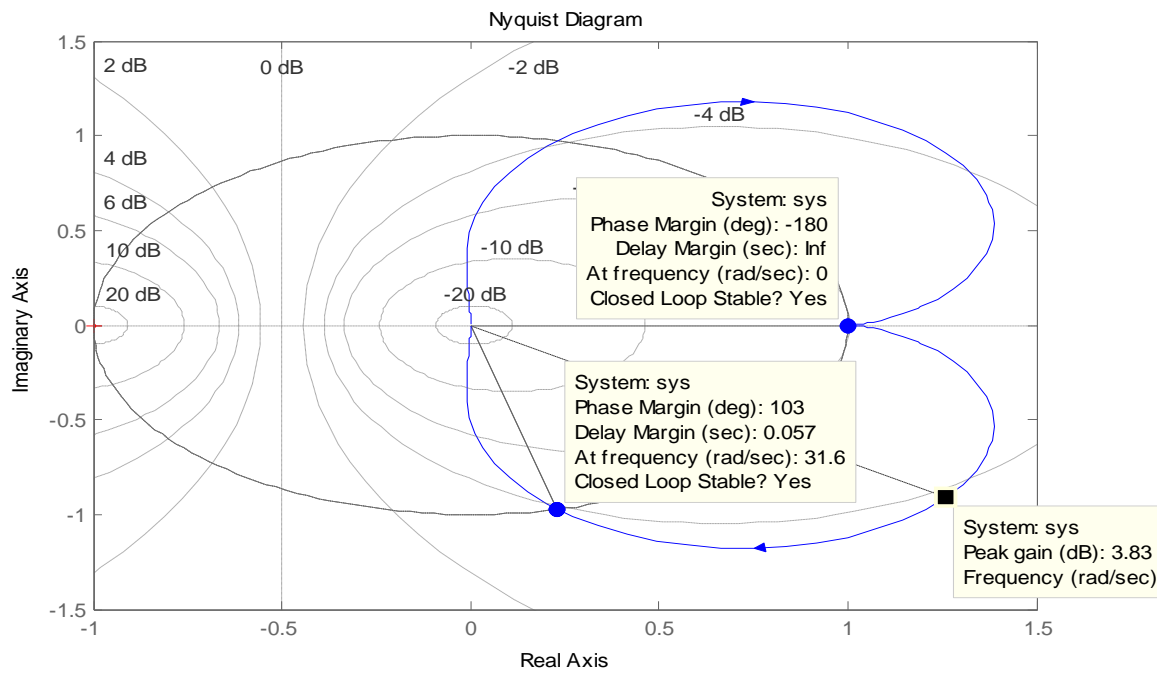


Figure 13. Nyquist plot for for $(20s+500)/(s^2+20s+500)$

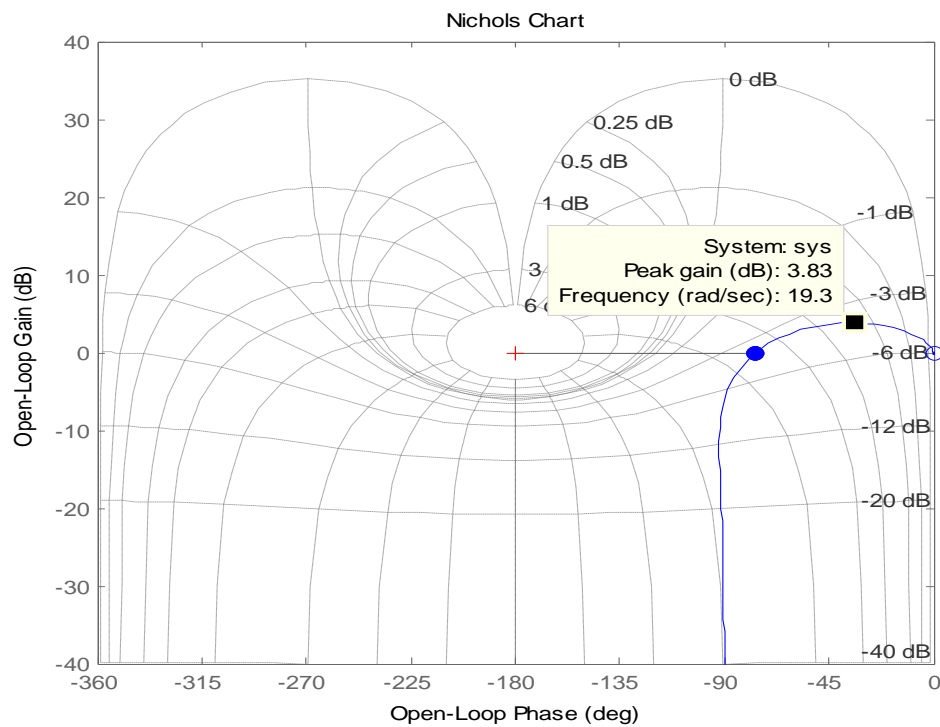


Figure 14. Nichols plot for for $(20s+500)/(s^2+20s+500)$

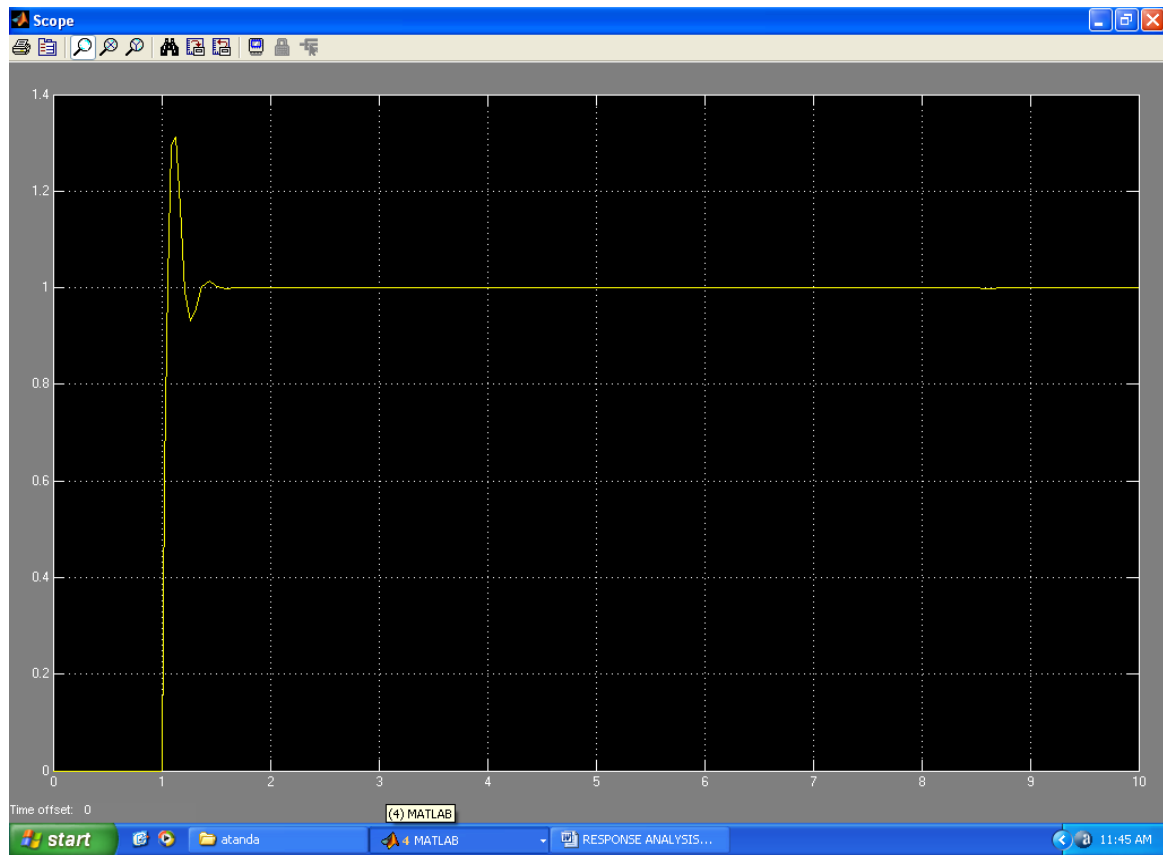


Figure 15. Response to step input response at a step time of 1 sec

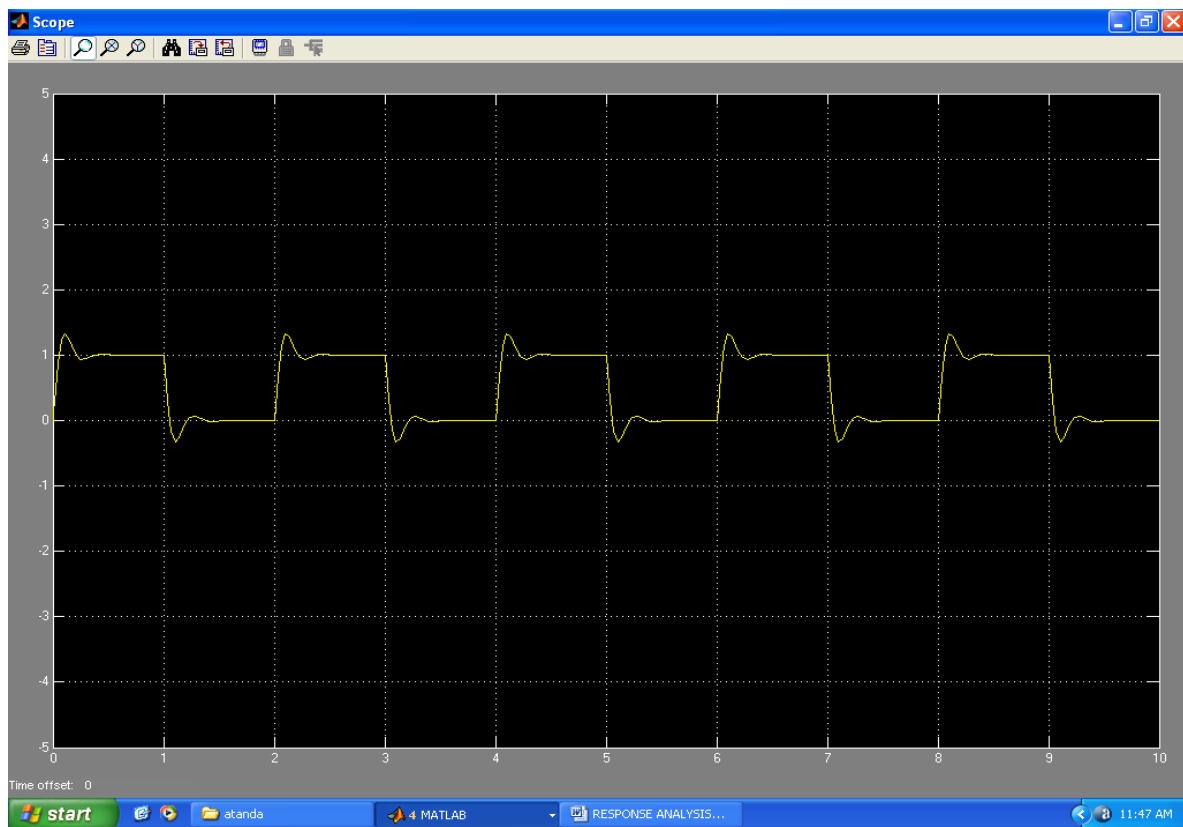


Figure 16. Response to pulse inputs(undulating layers on road surfaces)

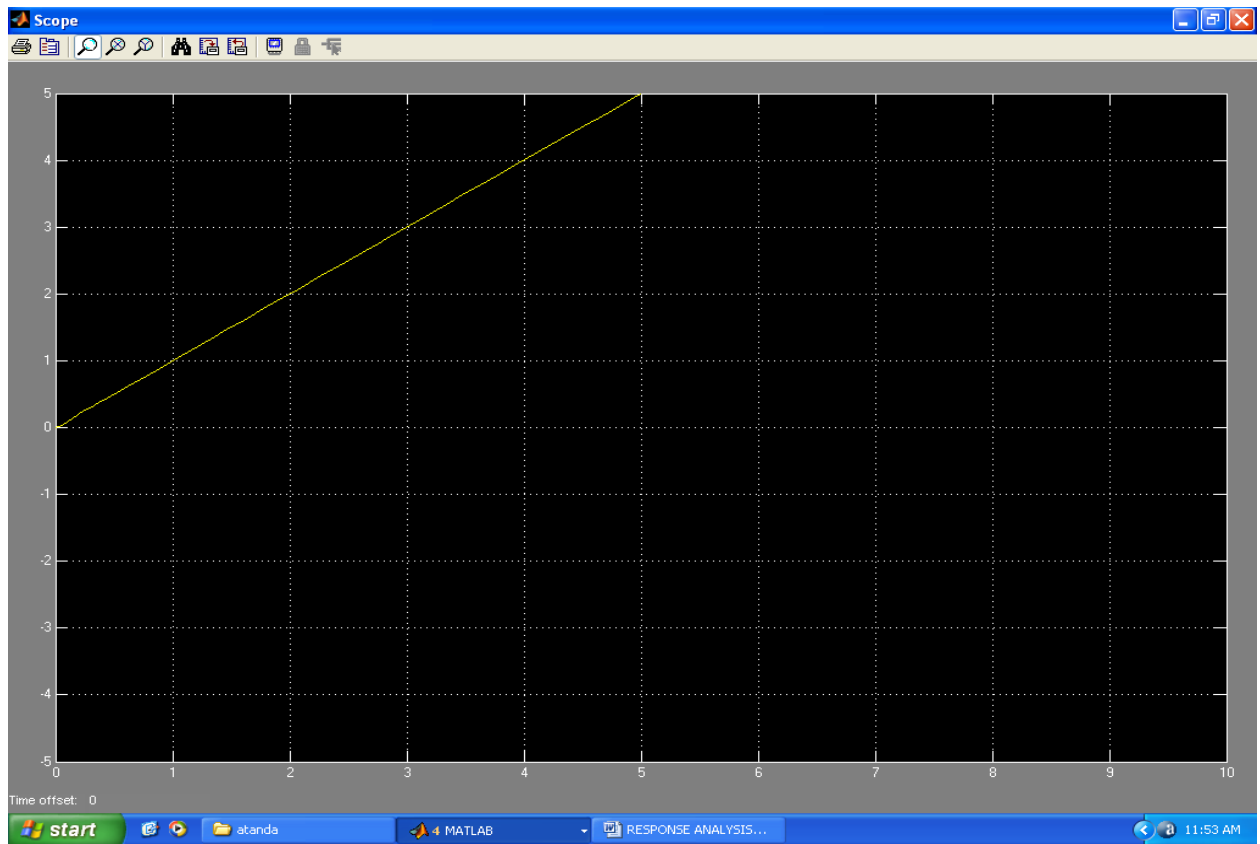


Figure 17. Response to ramp input of slope 1

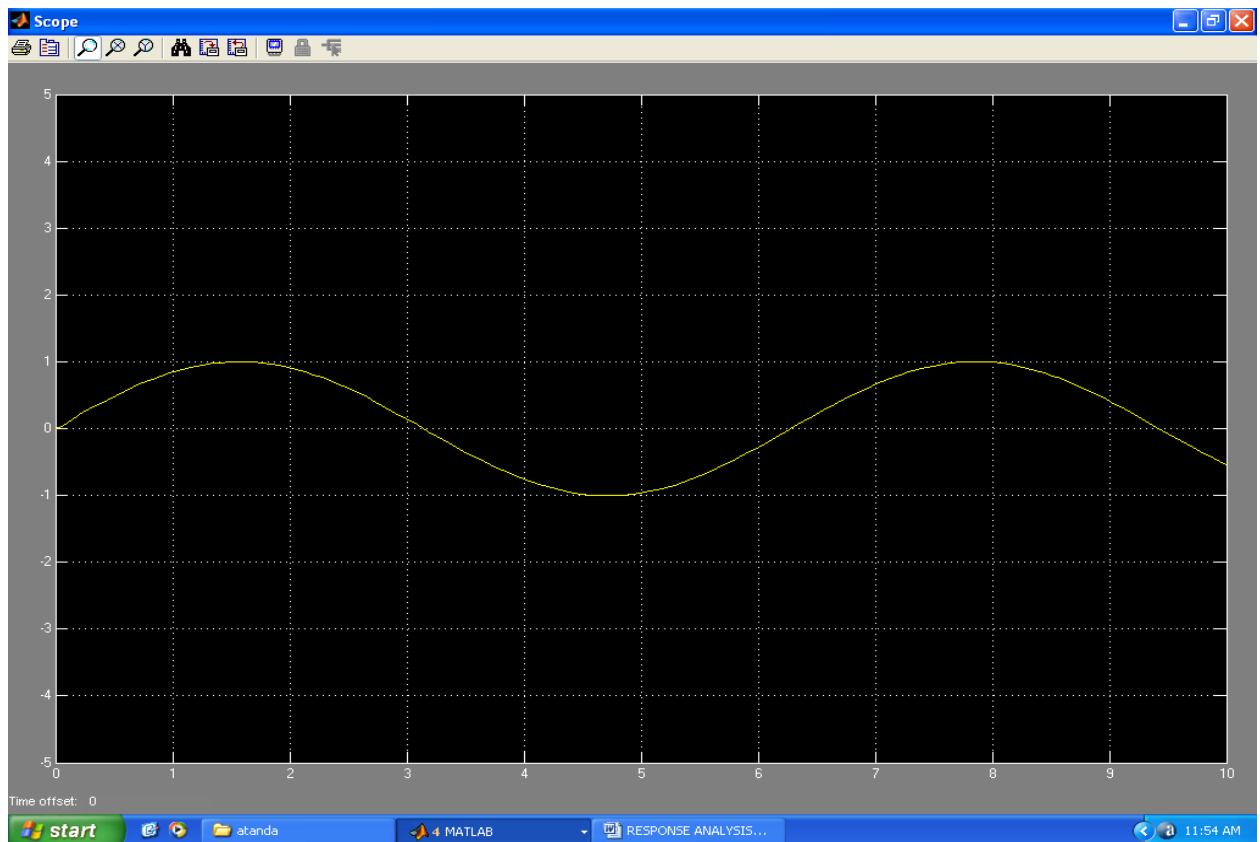


Figure 18. Response to sinusoidal input (bumps and depths on road surfaces)

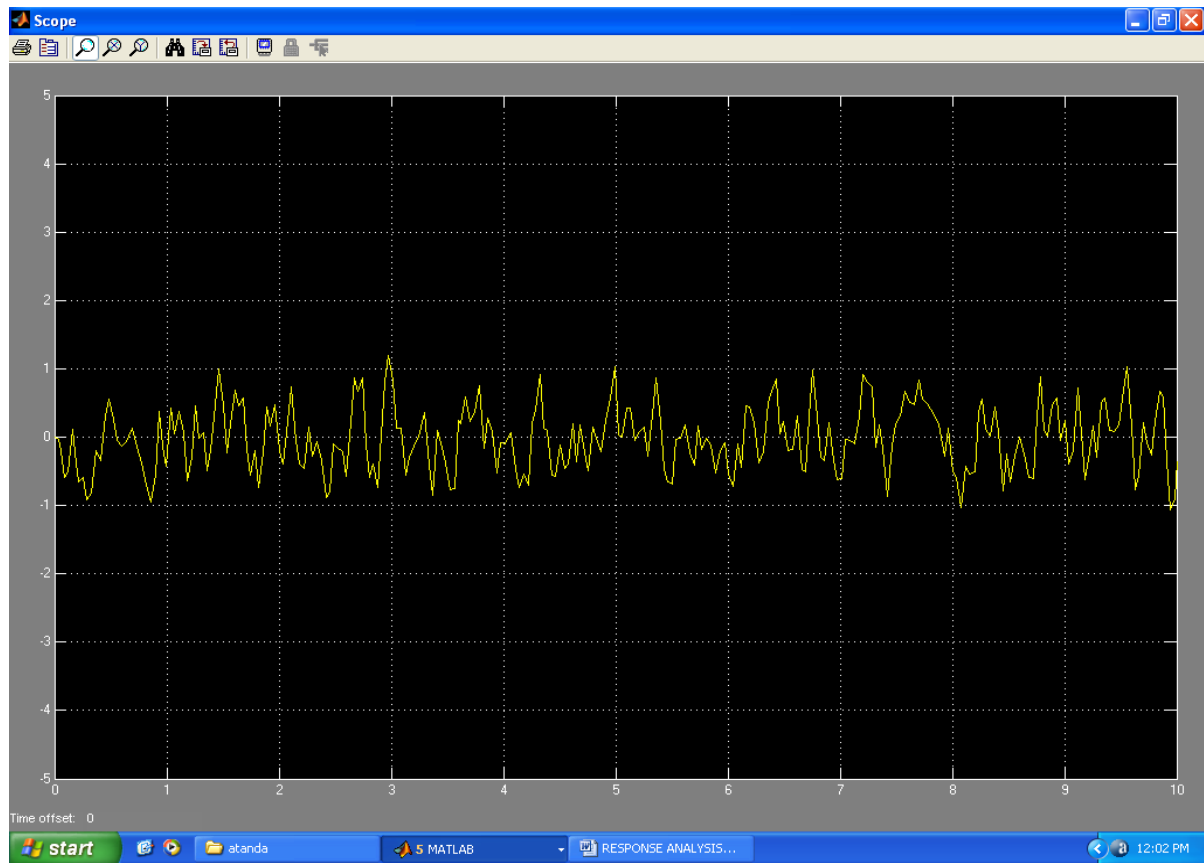


Figure 19. Response to random inputs

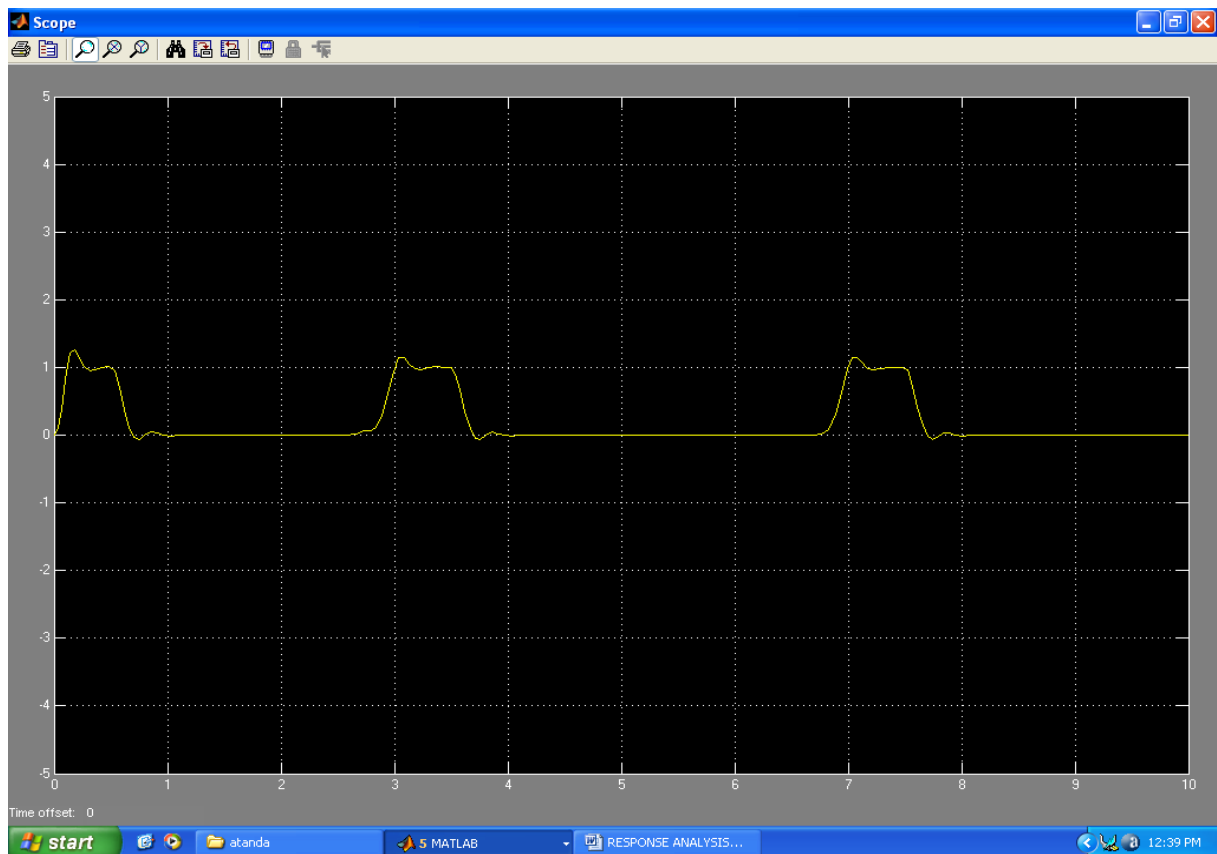


Figure 20. Response to square wave inputs

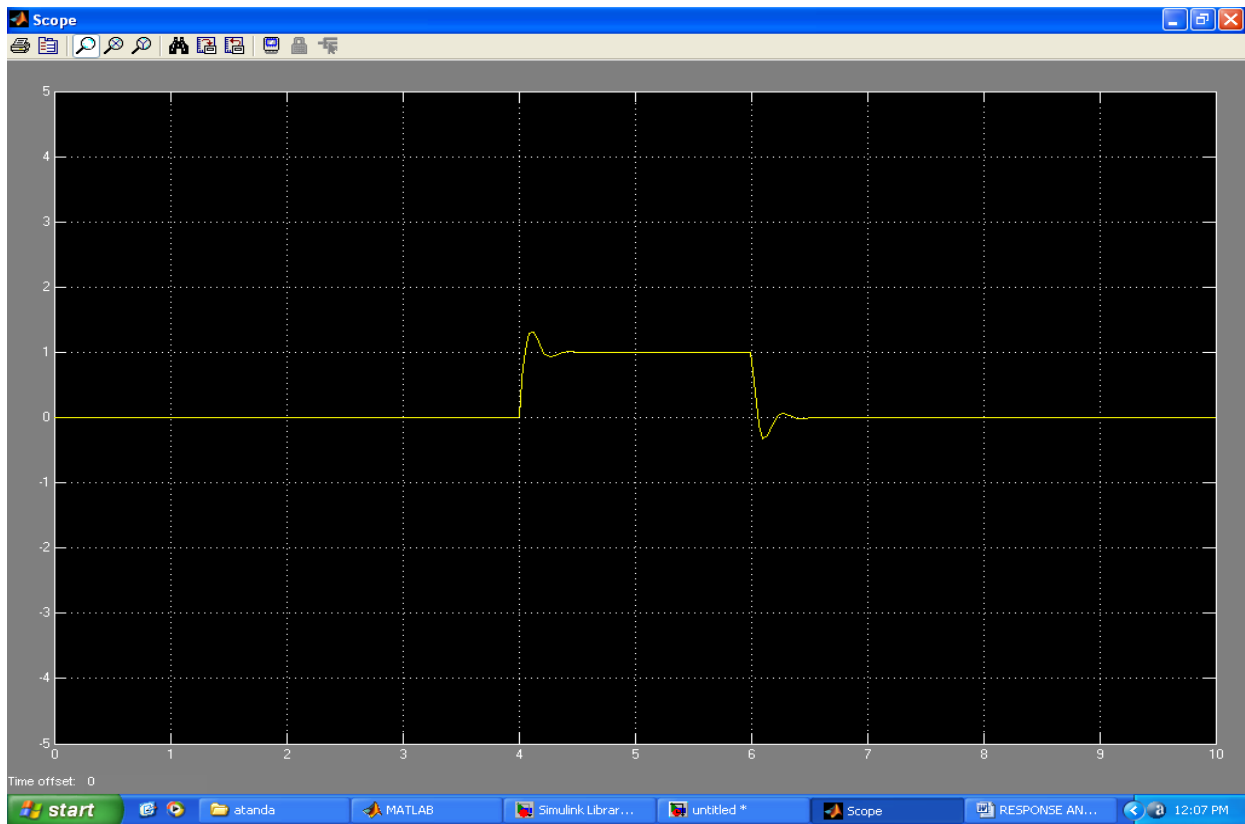


Figure 21. Output of Sharp square input and descent

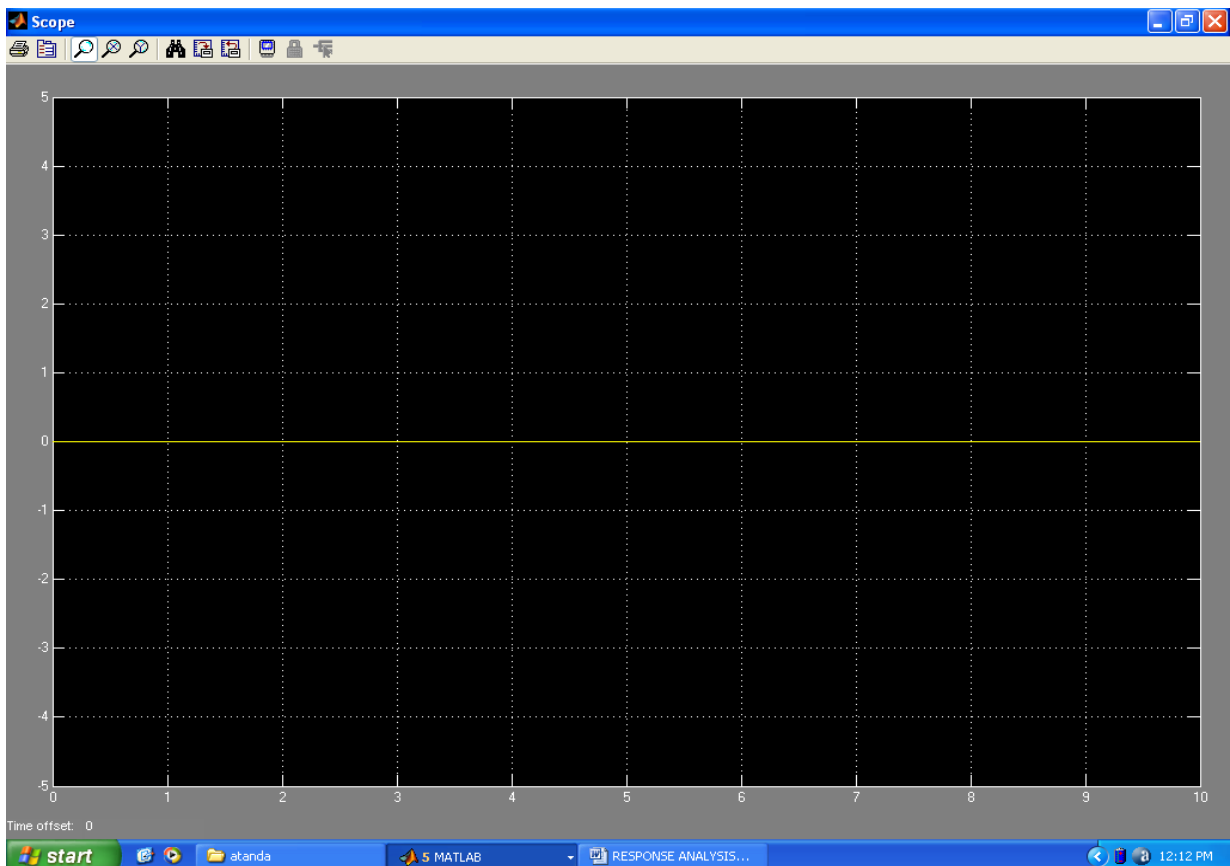


Figure 22. Response to no input (smooth road)

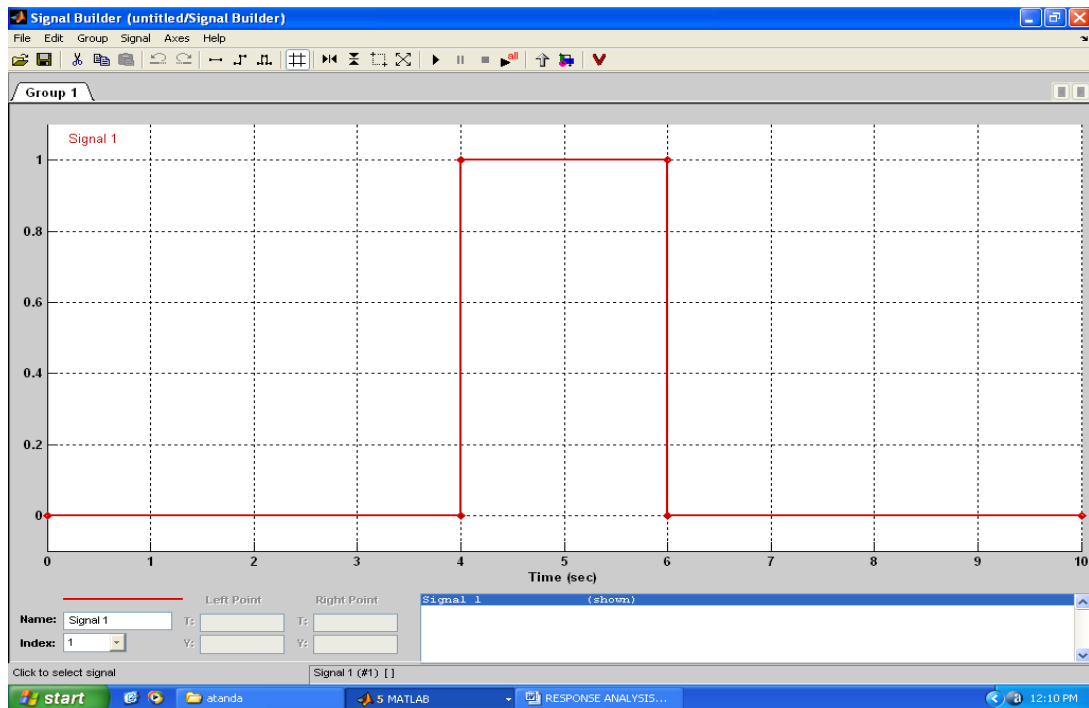


Figure 23. Use of signal builder for input signals

4. Conclusions

Auto-suspension system for compensators using Matlab commands and simulink has been done in this work. Using MATLAB root locus plot, the system could be re-designed by choosing new locus points and the new gains and damping ratios could be obtained. With the rlocfind command, the gains in the graphics window and the damping ratio could be found as well. With this a better design of the system could be obtained by compensating the system. This brings a dynamism into the design system.

With Simulink, the user has to obtain the poles first using the rootlocus plot. This plot gives the open loop zero and open loop poles for the system. These values are then input into the transfer function property forms. Thus, it is important when using Simulink to work with both the rootlocus plot and the Simulink transfer forms. It is the input into the transfer functions that brings out the responses of the system to various input signals. Input signals can be obtained using the signal buider.

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