Simulink-based dynamic simulation of an accelerometer mounted on an automobile riding over a bumpy road.

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INTRODUCTION

Simulink is a block diagram environment for multidomain simulation and Model-Based Design.

- Model hierarchical subsystems with predefined library blocks.
- Simulate the dynamic behavior of your system and view results as the simulation runs.
- Connect your model to hardware for real-time testing.

PROBLEM STATEMENT

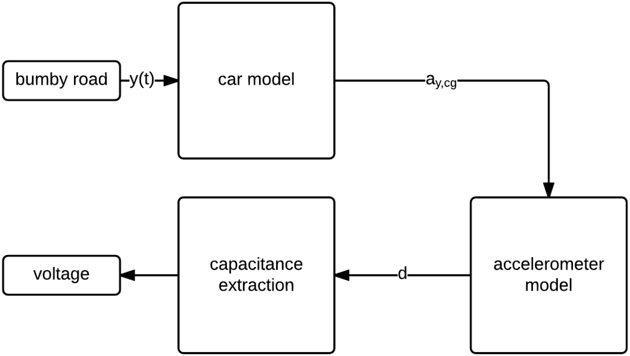
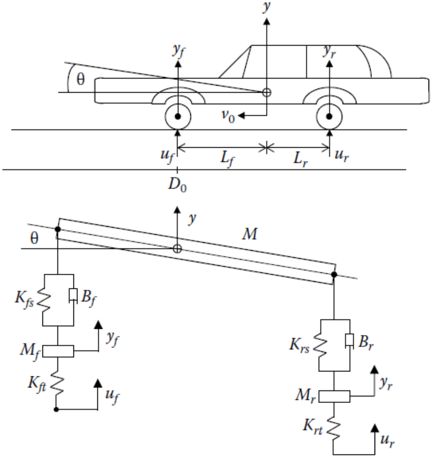


Figure: block diagram of the system.

SUBSYSTEMS

- Car model.
- Accelerometer model.
- Capacitance Extraction model.

CAR MODEL



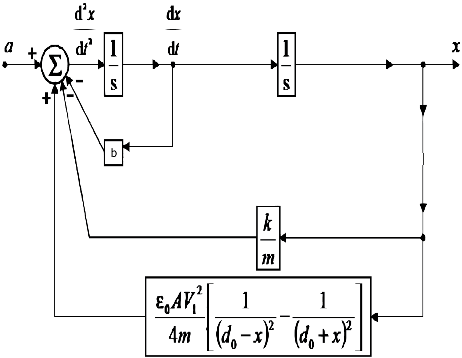
Model from "Simulation of Dynamic Systems with MATLAB and Simulink" by Randal Allen and Harold Klee.

State space model.

$$x_1 = y, \quad x_3 = y_f, \quad x_5 = y_r, \quad x_7 = \theta,$$
$$x_2 = \dot{y}, \quad x_4 = \dot{y}_f, \quad x_6 = \dot{y}_r, \quad x_8 = \dot{\theta},$$

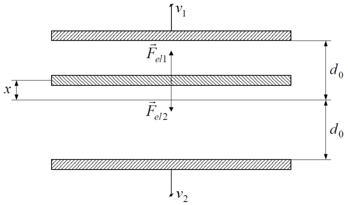
$$\begin{aligned}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= \frac{-(K_{fs}+K_{rs})}{M}x_1 - \frac{(B_f+B_r)}{M}x_2 + \frac{K_{fs}}{M}x_3 + \frac{B_f}{M}x_4 + \frac{K_{rs}}{M}x_5 + \frac{B_r}{M}x_6 \\
&\quad + \frac{(K_{rs}L_r - K_{fs}L_f)}{M}x_7 + \frac{(B_rL_r - B_fL_f)}{M}x_8 \\
\dot{x}_3 &= x_4 \\
\dot{x}_4 &= \frac{K_{fs}}{M_f}x_1 + \frac{B_f}{M_f}x_2 - \frac{(K_{fs}+K_{ft})}{M_f}x_3 - \frac{B_f}{M_f}x_4 + \frac{K_{fs}L_f}{M_f}x_7 + \frac{B_fL_f}{M_f}x_8 + \frac{K_{ft}}{M_f}u_f \\
\dot{x}_5 &= x_6 \\
\dot{x}_6 &= \frac{K_{rs}}{M_r}x_1 + \frac{B_r}{M_r}x_2 - \frac{(K_{rs}+K_{rt})}{M_r}x_5 - \frac{B_r}{M_r}x_6 - \frac{K_{rs}L_r}{M_r}x_7 - \frac{B_rL_r}{M_r}x_8 + \frac{K_{rt}}{M_r}u_r \\
\dot{x}_7 &= x_8 \\
\dot{x}_8 &= \frac{(K_{rs}L_r - K_{fs}L_f)}{I}x_1 + \frac{(B_rL_r - B_fL_f)}{I}x_2 + \frac{K_{fs}L_f}{I}x_3 + \frac{B_fL_f}{I}x_4 \\
&\quad - \frac{K_{rs}L_r}{I}x_5 - \frac{B_rL_r}{I}x_6 - \frac{(K_{fs}L_f^2 + K_{rs}L_r^2)}{I}x_7 - \frac{(B_fL_f^2 + B_rL_r^2)}{I}x_8
\end{aligned}$$

ACCELEROMETER MODEL



$$m\frac{d^2y}{dt^2} = m\frac{d^2x}{dt^2} + b(x)\frac{dx}{dt} + kx - F_{el}.$$

Electrostatic force.

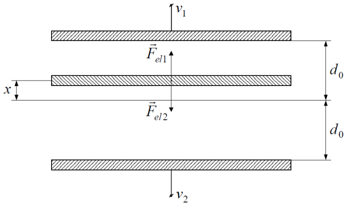


$$F_{el} = F_{el1} - F_{el2} = \frac{\varepsilon_0 A V_1^2}{4}\left[\frac{1}{(d_0 - x)^2} - \frac{1}{(d_0 + x)^2}\right],$$

$$F_{el1} = \frac{\varepsilon_0 A}{4}\frac{V_1^2}{(d_0 - x)^2},$$

$$F_{el2} = \frac{\varepsilon_0 A}{4}\frac{V_1^2}{(d_0 + x)^2}.$$

CAPACITANCE EXTRACTION MODEL.



$$C_1 = \frac{\varepsilon_0 \varepsilon_r A}{d_0 - x} = \frac{\varepsilon_0 \varepsilon_r A d_0}{d_0^2 - x^2} + \frac{\varepsilon_0 \varepsilon_r A x}{d_0^2 - x^2},$$

$$C_2 = \frac{\varepsilon_0 \varepsilon_r A}{d_0 + x} = \frac{\varepsilon_0 \varepsilon_r A d_0}{d_0^2 - x^2} - \frac{\varepsilon_0 \varepsilon_r A x}{d_0^2 - x^2}.$$

Change in capacitance.

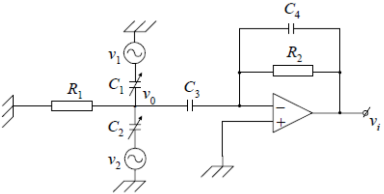
$$C_1 \cong C_0 + \Delta C,$$
$$C_2 \cong C_0 - \Delta C,$$

where

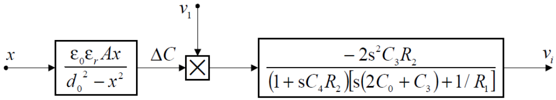
$$C_0 = \frac{\varepsilon_0 \varepsilon_r A}{d_0},$$

$$\Delta C = \frac{\varepsilon_0 \varepsilon_r A x}{d_0^2 - x^2}.$$

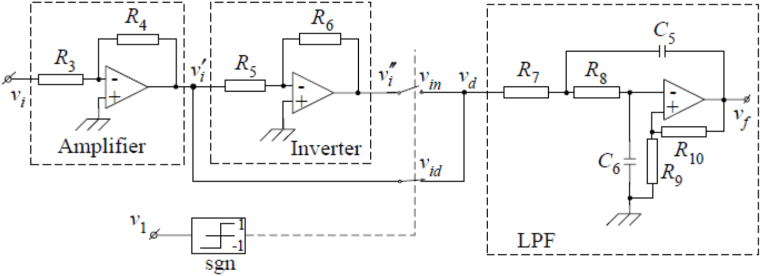
Capacitance extraction circuit.



$$V_i(\mathrm{s}) = -\frac{2\mathrm{s}^2 C_3 R_2 \Delta C V_1(\mathrm{s})}{(1+\mathrm{s}C_4R_2)\left[\mathrm{s}(2C_0+C_3)+1/R_1\right]}.$$



Low pass filter.

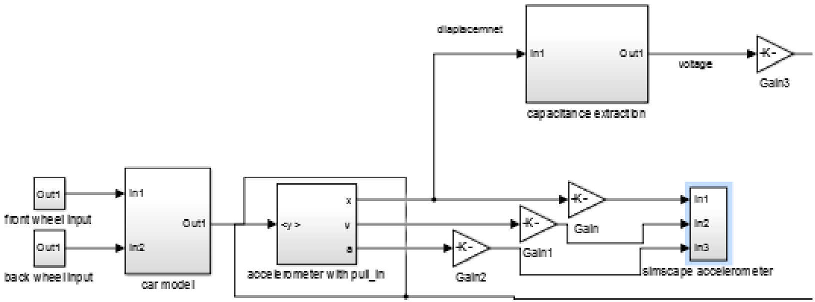


Low pass filter.

$$\frac{V_f(s)}{V_d(s)} = \frac{k_A}{a_2 s^2 + a_1 s + 1}.$$

$$k_a = -R_4 / R_3,$$
$$k_A = 1 + R_{10} / R_9,$$
$$a_2 = R_7 R_8 R_9 C_5 C_6,$$
$$a_1 = C_6(R_7 + R_8) - C_5 R_7 R_{10} / R_9$$

FINAL SYSTEM IN SIMULINK



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[1] T.L. Grigorie. The matlab/simulink modeling and numerical simulation of an analogue capacitive micro-accelerometer. part 1: Open loop. In *Perspective Technologies and Methods in MEMS Design, 2008. MEMSTECH 2008.*, pages 105–114, May 2008.

[2] Randal Allen Harold Klee. *Simulation of Dynamic Systems with MATLAB and Simulink*. CRC Press.

[3] Stephen D. Senturia. *Microsystem Design*. Springer.

Thank you