

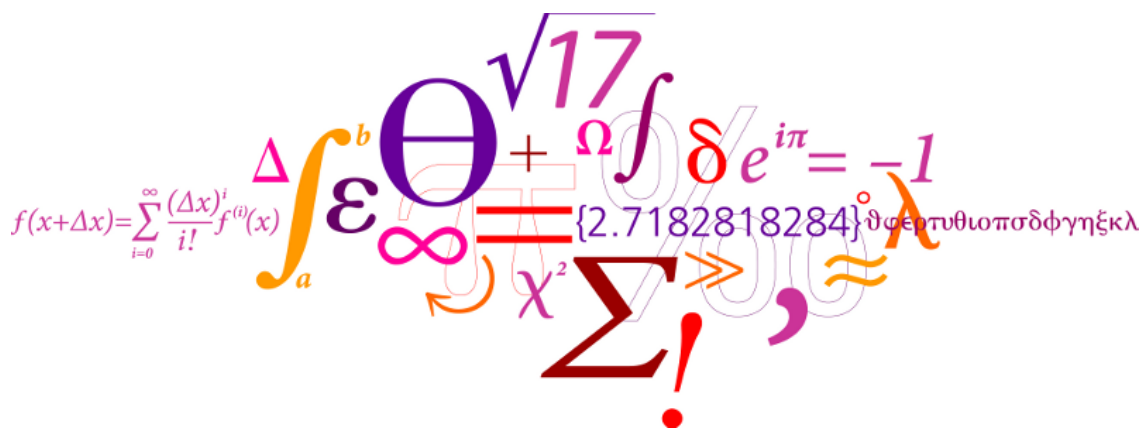
# 31310 LINEAR CONTROL DESIGN 2

COMPULSORY ASSIGNMENT 2015 : LOUDSPEAKER CONTROL

by

KATLEEN BLANCHET s150798

TITOUAN BOULMIER s150810



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Technical University of Denmark  
Department of Electrical Engineering

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## Part I

# Exercise 1: Distortion Attenuation for Loudspeakers

Moving-coil Loudspeakers

## 1 Loudspeakers electrical equivalent circuit

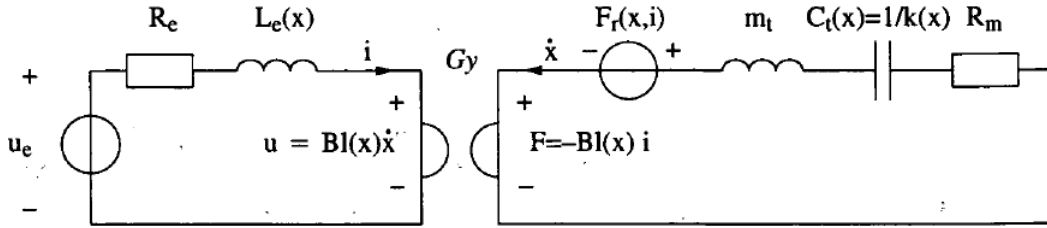


Figure 1: Electrical equivalent lumped element model of the voltage driven electrodynamic loudspeaker for low frequencies. The coupling between the electrical and mechanical domain is performed through the gyrator with gy-ration constant  $Bl(x)$ .

$$u_e = R_e i + \frac{dL_e(x)}{dx} \frac{dx}{dt} i + L_e(x) \frac{di}{dt} + Bl(x) \frac{dx}{dt} \quad (1)$$

$$Bl(x) i = m_t \frac{d^2 x}{dt^2} + R_m \frac{dx}{dt} + k(x) x - \frac{1}{2} \frac{dL_e(x)}{dx} i^2 \quad (2)$$

where

$$Bl(x) = Bl_0 + b_1 x + b_2 x^2 \quad (3)$$

$$L_e(x) = L_{e0} + l_1 x + l_2 x^2 \quad (4)$$

$$k(x) = k_0 + k_1 x + k_2 x^2 \quad (5)$$

### 1.1 Problem 1

By means of Eqs 1, 2, 3, 4 and 5, we can identify 3 state variables  $i$ ,  $x$  and  $\dot{x}$ . We can also identify the input  $u_e$ .

$$\mathbf{x} = \begin{pmatrix} i \\ x \\ \dot{x} \end{pmatrix} \text{ and } \mathbf{u} = (u_e)$$

Then, we can derive the nonlinear dynamical state space model to obtain

$$\dot{i} = \frac{u_e - (R_e + (l_1 + 2l_2x)\dot{x})i - (Bl_0 + b_1x + b_2x^2)\dot{x}}{L_{e0} + l_1x + l_2x^2} \quad (6)$$

$$\dot{x} = \dot{x} \quad (7)$$

$$\ddot{x} = \frac{(Bl_0 + b_1x + b_2x^2)\ddot{x} - R_m\dot{x} - (k_0 + k_1x + k_2x^2)x(2) + \frac{1}{2}(l_1 + 2l_2x)\dot{x}^2}{m_t} \quad (8)$$

In matrix format, we have

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}) + \mathbf{g}(\mathbf{x})\mathbf{u} \quad (9)$$

with

$$\mathbf{f}(\mathbf{x}) = \begin{pmatrix} \frac{u_e - (R_e + (l_1 + 2l_2x(2))x(3))x(1) - (Bl_0 + b_1x(2) + b_2x(2)^2)x(3)}{L_{e0} + l_1x(2) + l_2x(2)^2} \\ x(3) \\ \frac{(Bl_0 + b_1x(2) + b_2x(2)^2)x(1) - R_mx(3) - (k_0 + k_1x(2) + k_2x(2)^2)x(2) + \frac{1}{2}(l_1 + 2l_2x(2))x(3)x(1)^2}{m_t} \end{pmatrix} \quad (10)$$

$$\mathbf{g}(\mathbf{x}) = \begin{pmatrix} 1 \\ 0 \\ 0 \end{pmatrix} \quad (11)$$

## 1.2 Problem 2

## References