Lecture 6-1

Electrical Systems I

Development of Integrated Vehicle Control System of “Fine-X” Which Realized Freer Movement.

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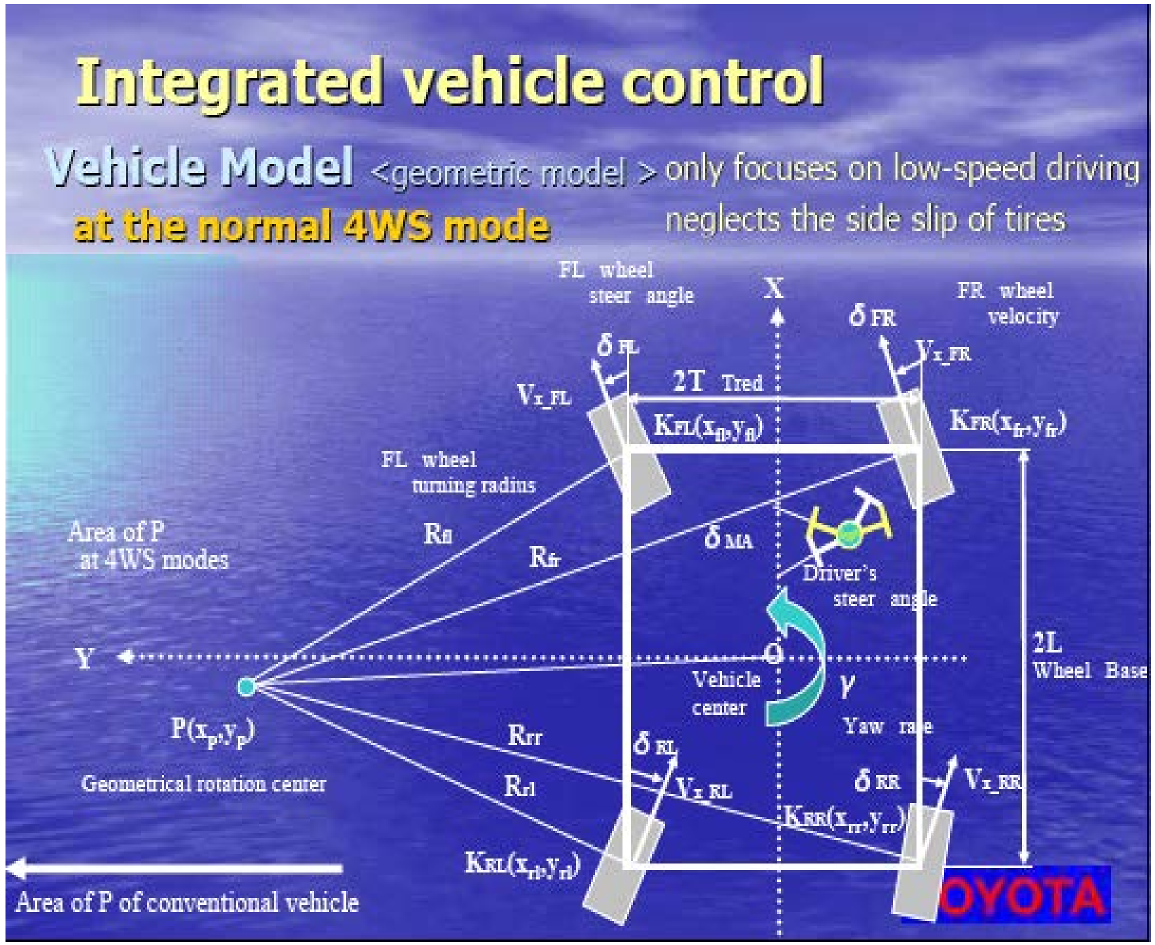
TOYOTA

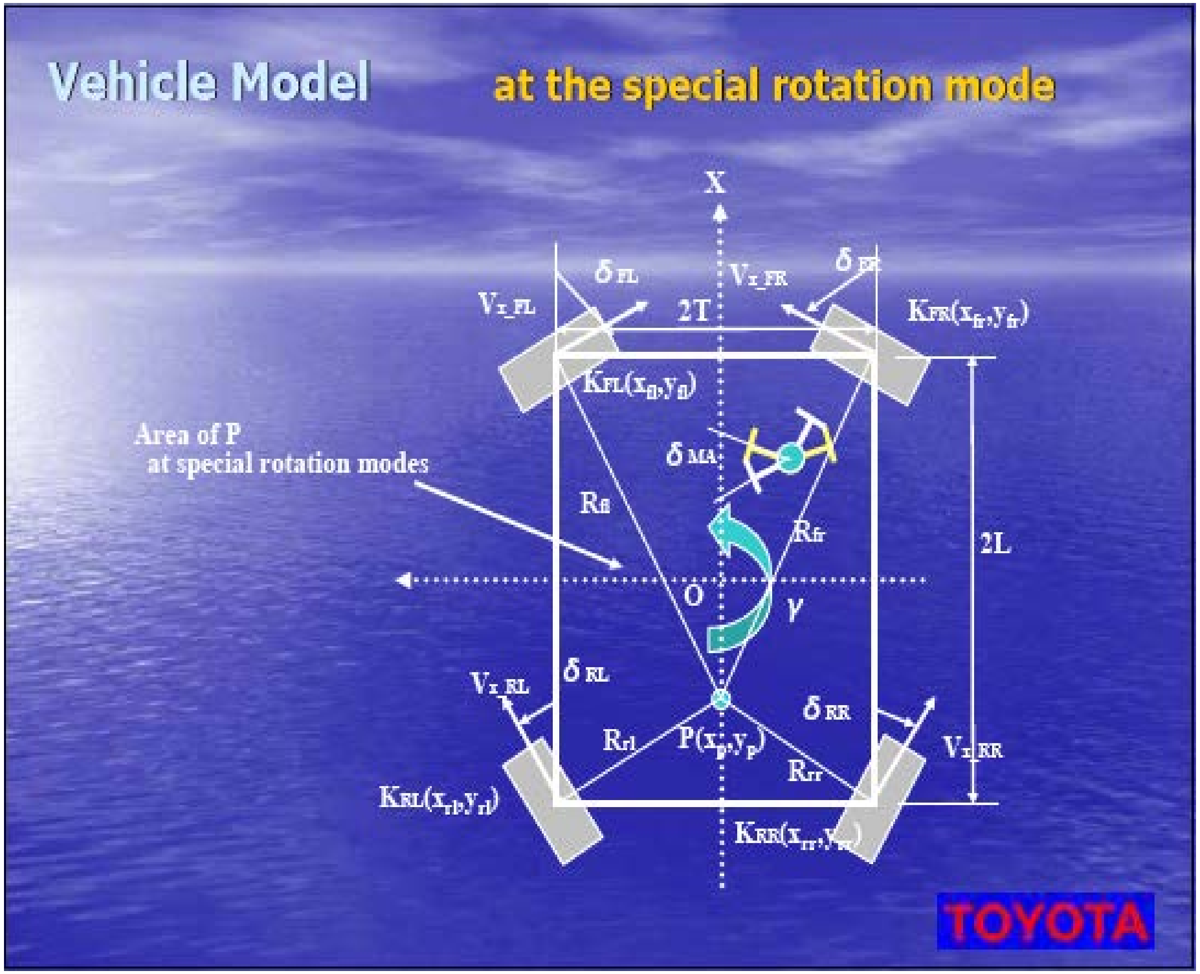
TOYOTA Freer Movement Control System

4Wheel independent drive
4wheel independent steering
4wheel independent braking
By 'wheel-in-motor'

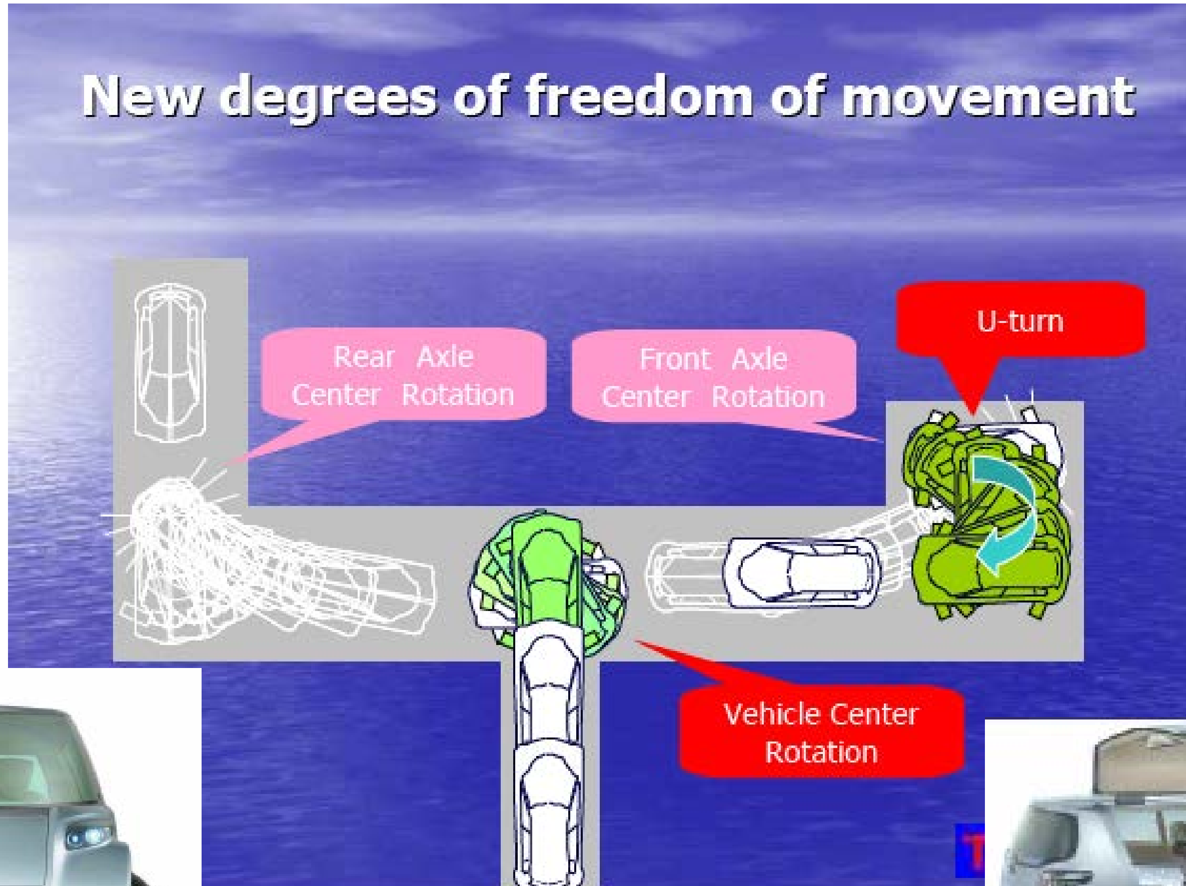
TOYOTA Freer Movement Control System



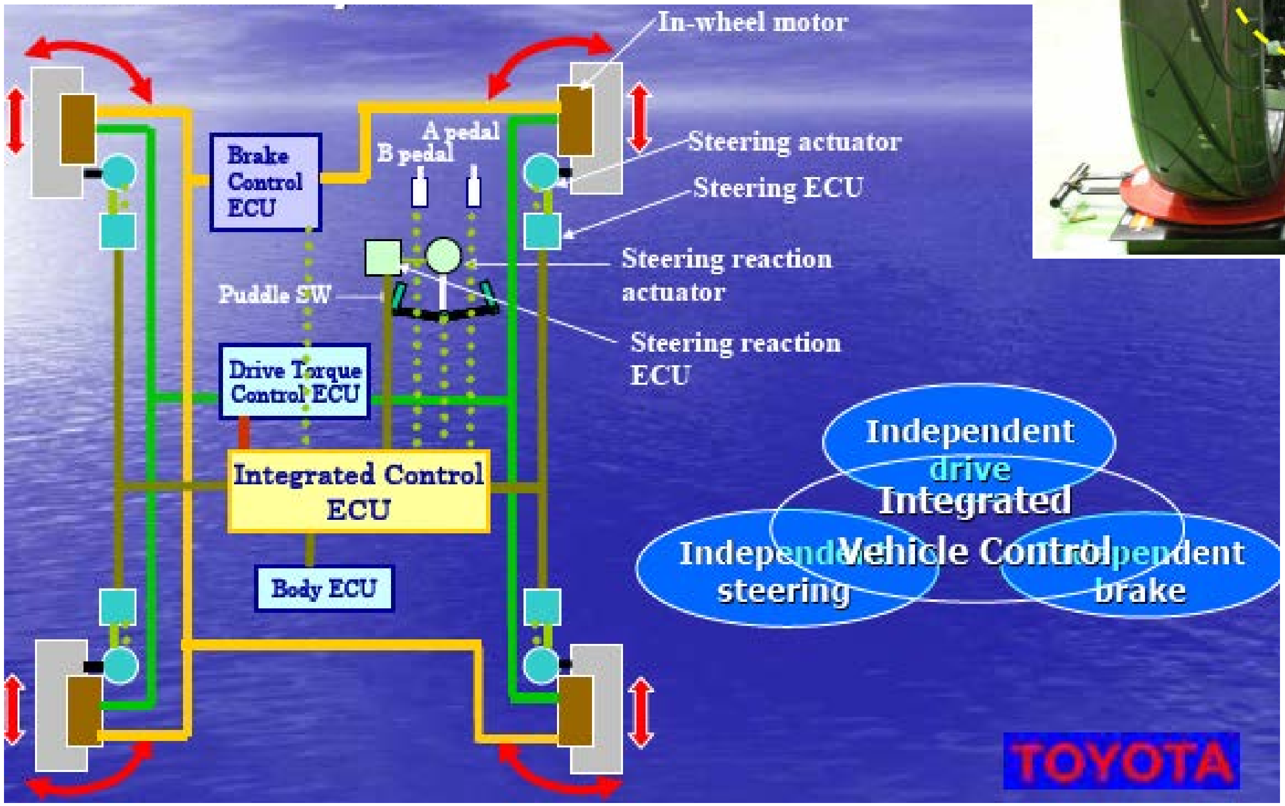
TOYOTA Freer Movement Control System

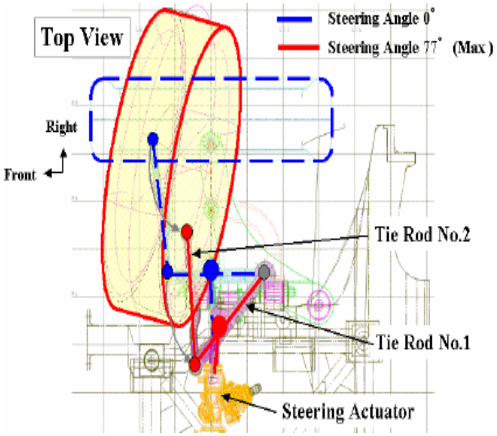


TOYOTA Freer Movement Control System for Auto-Parking

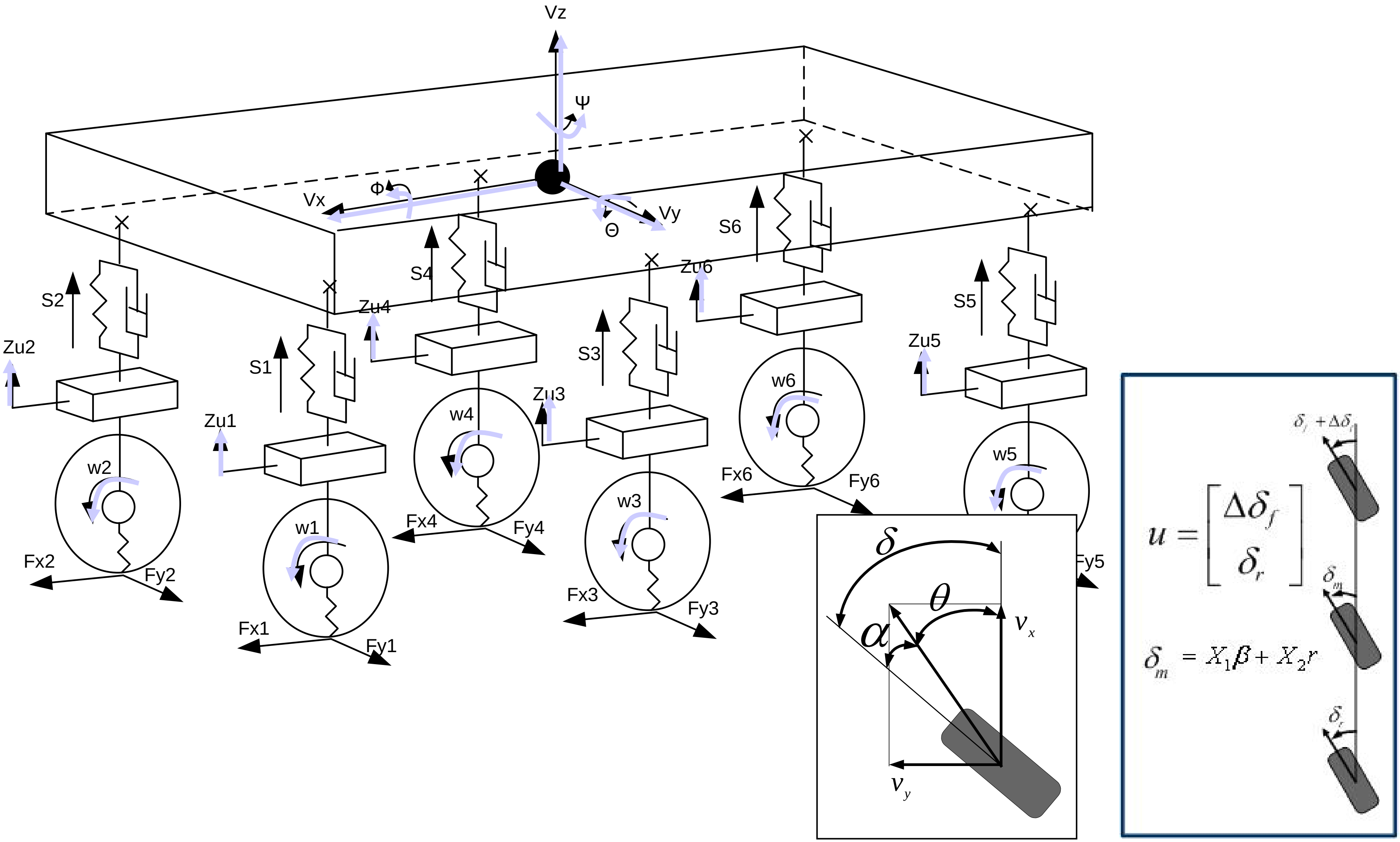


TOYOTA Freer Movement Control System for Auto-Parking

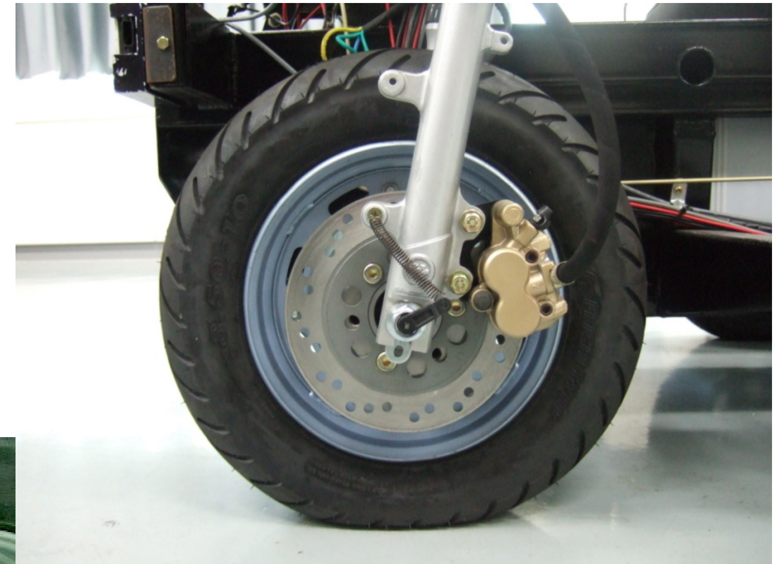




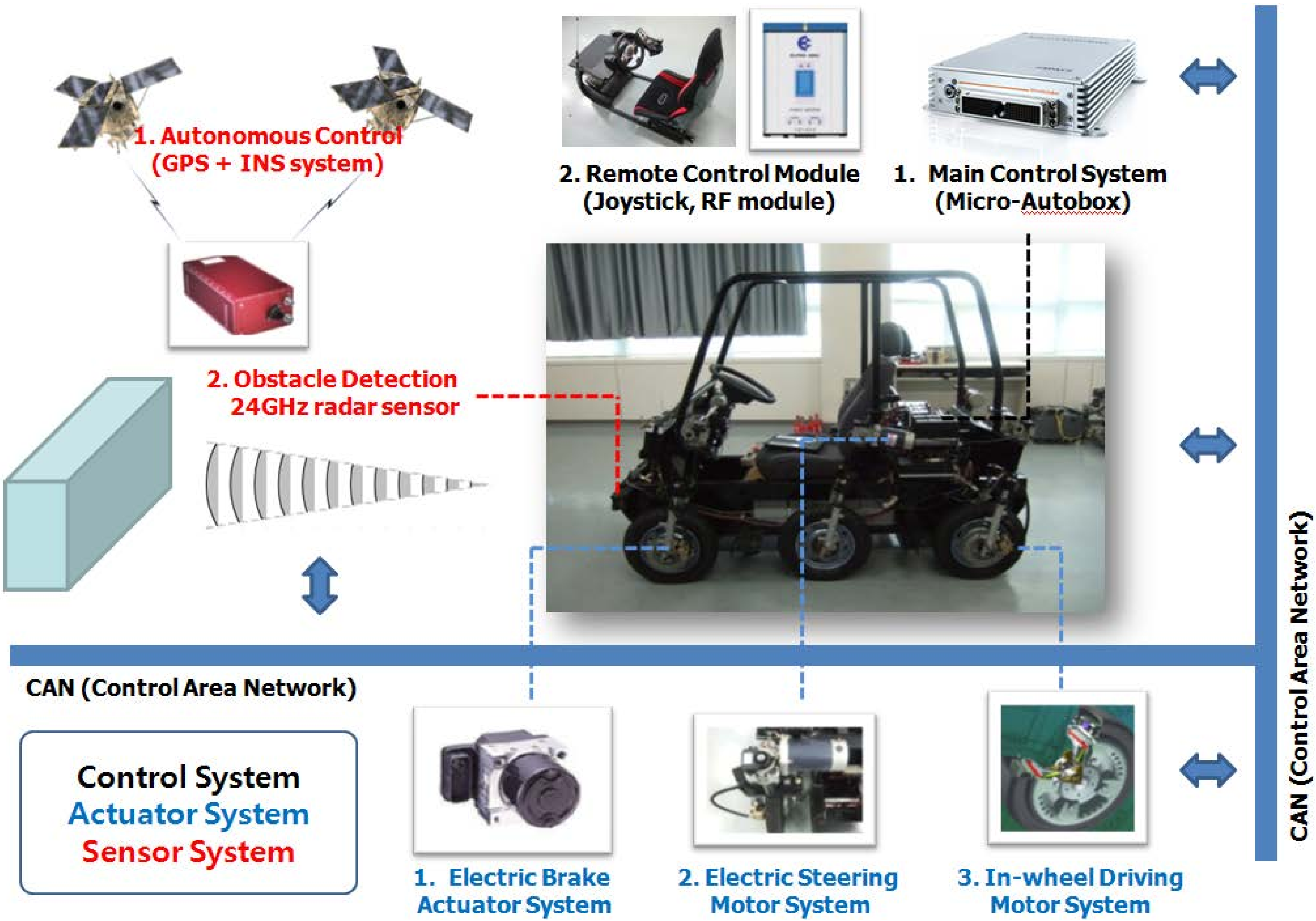
6WD6WS Vehicle



BLDC Wheel-in-Motor of 6WD6WS Vehicle



Configuration of 6WD6WS Vehicle



Sectional View of BLDC Motor

Video of 6WD/6WS Vehicle equipped with Wheel-in Motor

Parallel & Circular Turning

평행_제자리선회.wmv

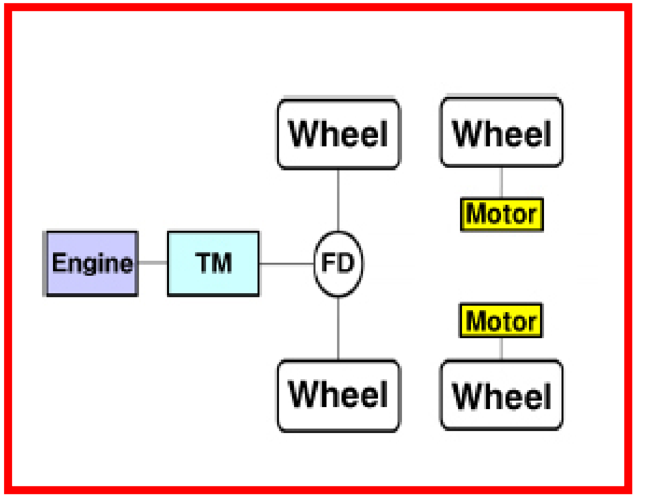
Remote Control

Remote_general_recent.avi

Autonomous Driving

Autonomous_path_tracking.avi

Hybrid and Electrical Vehicles



- **Advantages**
  - Minimized both costs and technical issues
  - Even weight distribution
  - Simplest packaging
  - Improved vehicle chassis control

- **Targets**
  - To maintain or improve on **Euro 4 emissions**
  - To achieve a **30% overall reduction in CO_2** tail pipe emissions of the baseline vehicle operating with the same fuel, over the NEDC cycle as per EC/98/69 and EC/70/220 for vehicles less than 3500kg.
  - Equivalent fuel economy ≥ **60mpg=25.4kpl** (50% improvement in mpg on baseline vehicle)

Hybrid and Electrical Vehicles

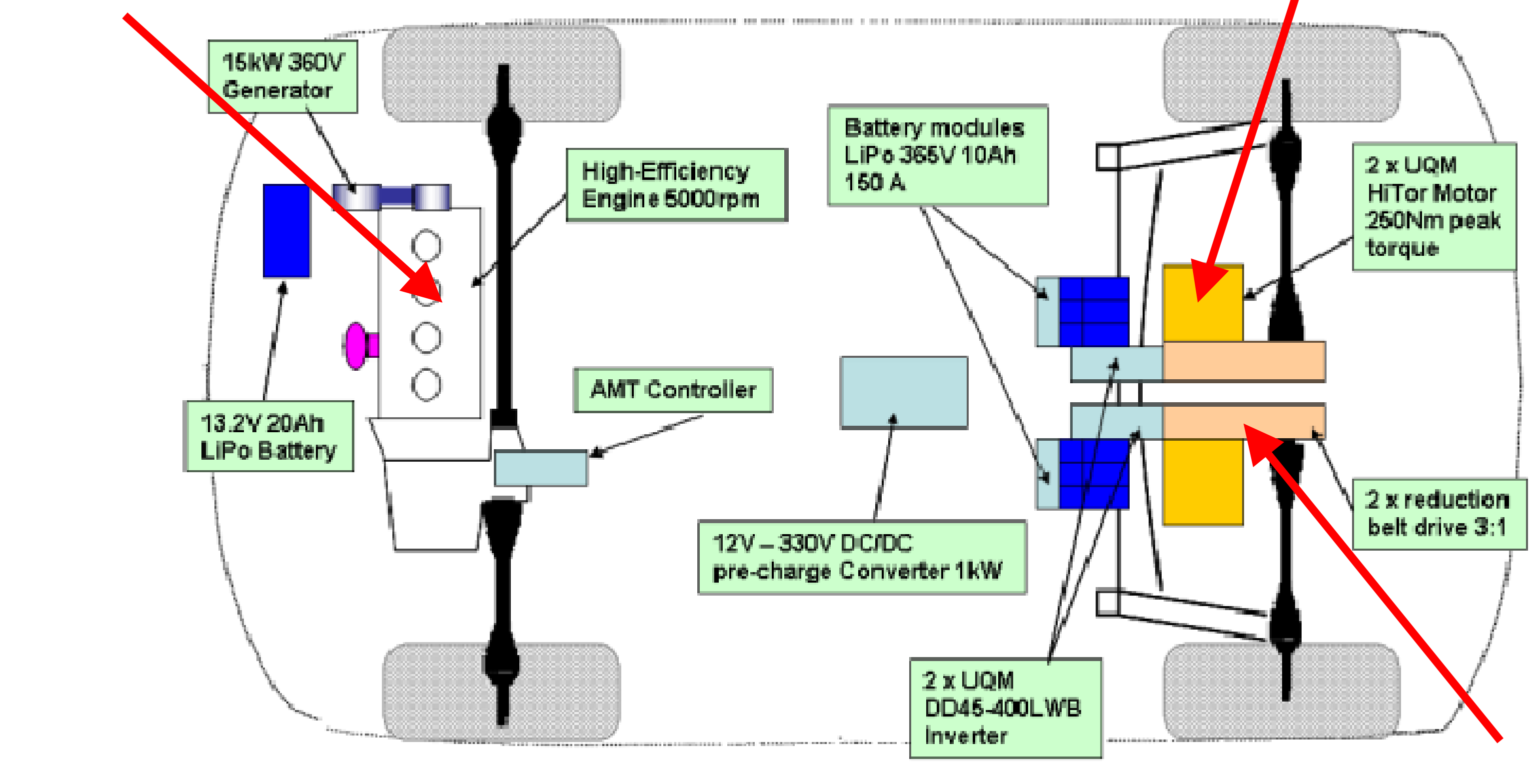
Skoda Fabia (Compact SUV)

Hybrid 4WD Vehicle Configuration

Developed by MIRA (Skoda Fabia)

35 KW / 250 Nm Peak Torque

1400 cc 100 HP ICE



A total weight of around 150kg:
motors = 2x45kg, inverters=2x15kg, structure=30kg

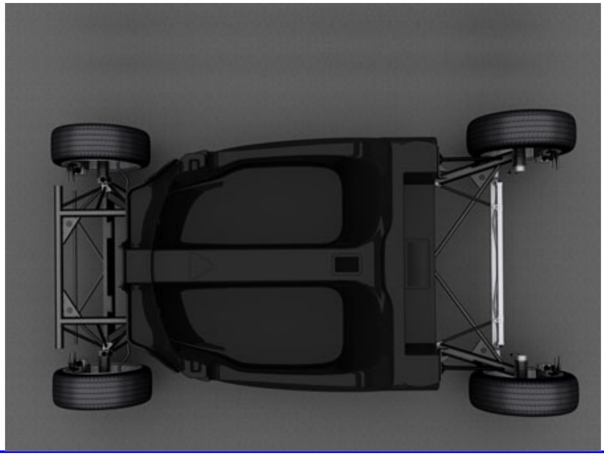
3:1 reduction belt drive
➔ Peak torque = 750 Nm

4 WD In-wheel Electric Vehicle

Michelin Active Wheel with in-wheel motor, suspension and brake system

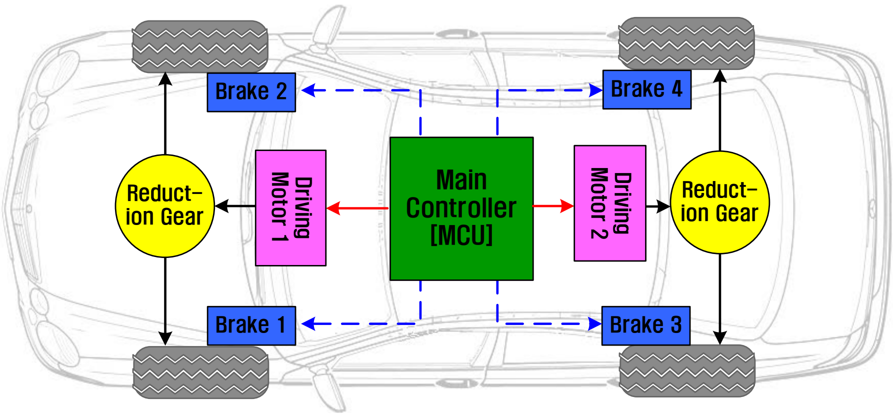
Electric vehicle equipped with Front two in-wheel motors

Electric vehicle equipped with four in-wheel motors

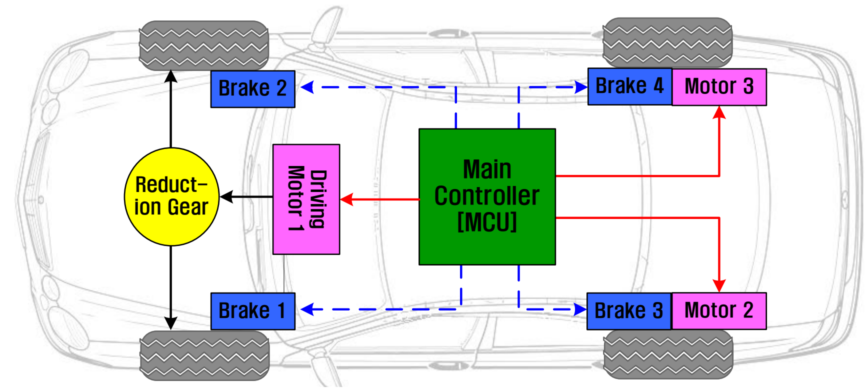


4 WD Electric Vehicle Combinations

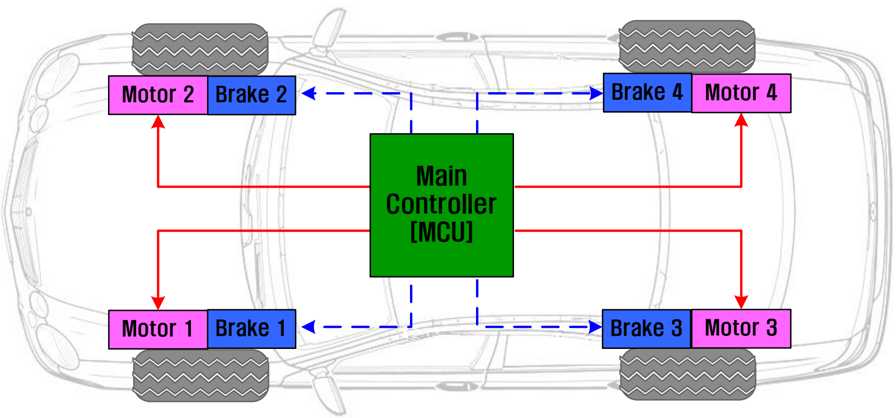
- **Front/rear Two In-line Motors**



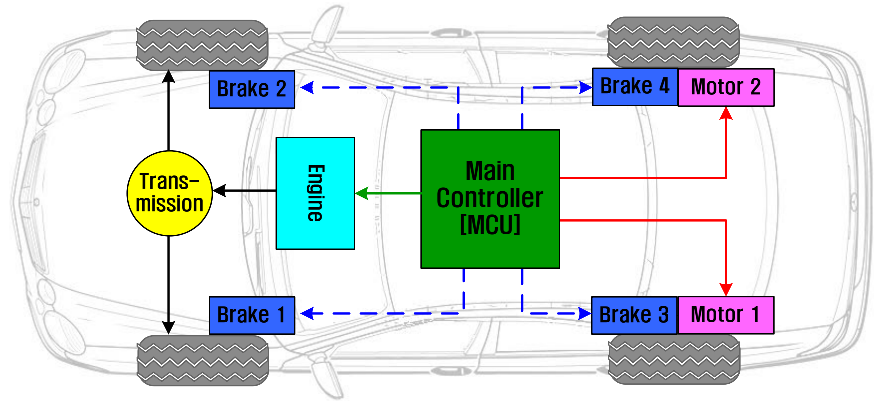
- **Front In-line Motor/Rear In-wheel motors**



- Four **In-wheel Motors**



- **Front Engine Drive/Rear Two In-wheel Motors**



6WD Skid Steering Vehicle

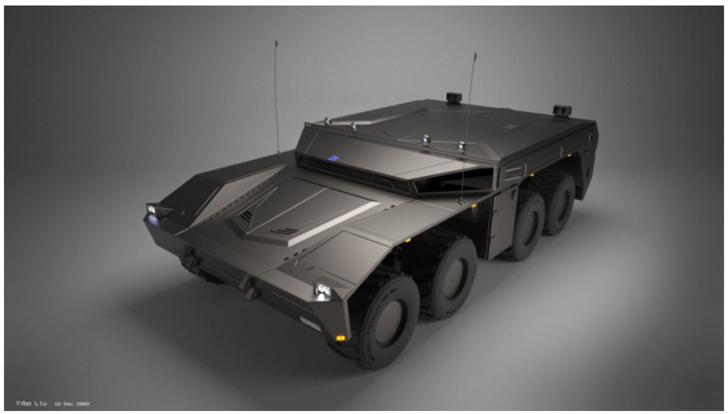
Crusher | **APD**

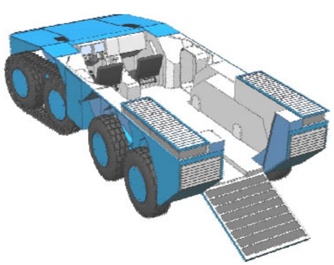
Crusher highlights.wmv

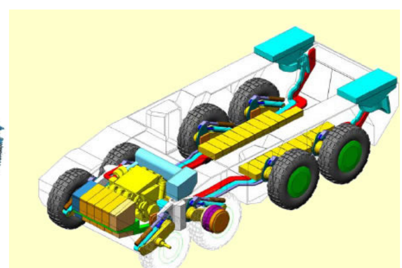
Autonomous Platform Demonstrator (APD) Overview.wmv

8WD/4WS Vehicle Equipped with 8 In-wheel Motor

AHED







AHED_8x8_vehicle_vedio.wmv

Basic Elements

- Active Elements: OP Amp etc.
  (Has transistors/amplifiers that require active source of power to work)

- Passive Elements: Inductor, Resistor, Capacitor etc.
  (Simply respond to an applied voltage or current.)

- Current : the rate of flow of charge

- Charge : (electric charge) the integral of current with respect to time [C]

$$i = \frac{dq}{dt} \qquad [\text{ampere}] = \frac{[\text{coulomb}]}{[\text{sec}]}$$

- Voltage : electromotive force needed to produce a flow of current in a wire [V]
  Change in energy as the charge is passed through a component.
  [V] = [J/C]

- Power: product of voltage and current

  [W] = [J/Sec]

Basic Elements - Resistance

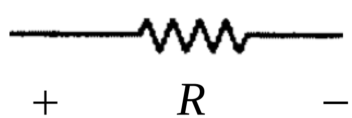
- Resistance : the change in voltage required to make a unit change in current.

Analogous to → Damping Element

$$R = \frac{Change\ \ in\ \ voltage}{Change\ \ in\ \ current} = \frac{[V]}{[A]} = [Ohm(\Omega)]$$

- Resistor

$$V_R = R \cdot i_R \qquad R = \frac{V_R}{i_R}$$



Basic Elements - Capacitance

- Capacitance: the change in the quantity of electric charge required to make a unit change in voltage.

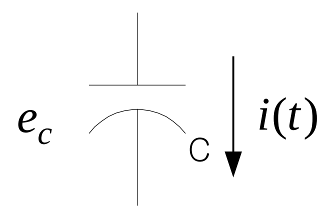
Analogous to → Spring Element (Stores Potential Energy)

$$C = \frac{[Coulomb]}{[V]} = [Farad\ (F)]$$

- Capacitor: two conductor separated by non-conducting medium.

$$i = dq/dt\,, \quad e_c = q/C \quad \rightarrow \quad i = C\frac{de_c}{dt}\,, \quad de_c = \frac{1}{C} i\, dt$$

$$\therefore e_c(t) = \frac{1}{C}\int_0^t i\, dt + e_c(0)$$



$$I(s) = CsV(s)\,, \quad V(s) = \frac{1}{Cs} I(s)$$

Basic Elements - Inductance

- Inductance: An electromotive force induced in a circuit, if the circuit lies in a time –varying magnetic field.

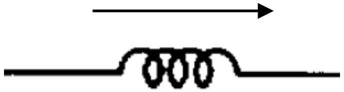
Analogous to → Inertia Element (Stores Kinetic Energy)

$$L = \frac{[V]}{[A/\sec]} = [Henry\,(H)]$$

- Inductor:

$$e_L = L\frac{di_L}{dt} \qquad V(s) = LsI(s)$$

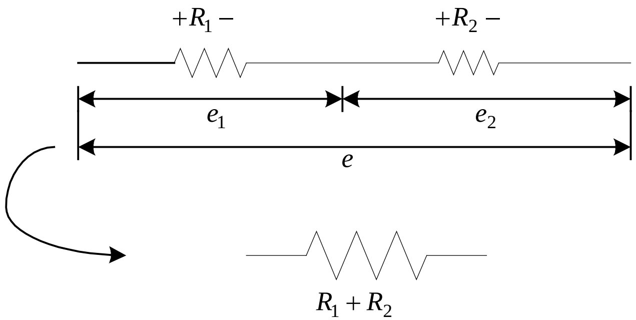
$$\therefore\ i_L(t) = \frac{1}{L}\int_0^t e_L\,dt + i_L(0) \qquad I(s) = \frac{1}{Ls}V(s)$$



$i(t)$

Series & Parallel Resistance

- Series Resistance

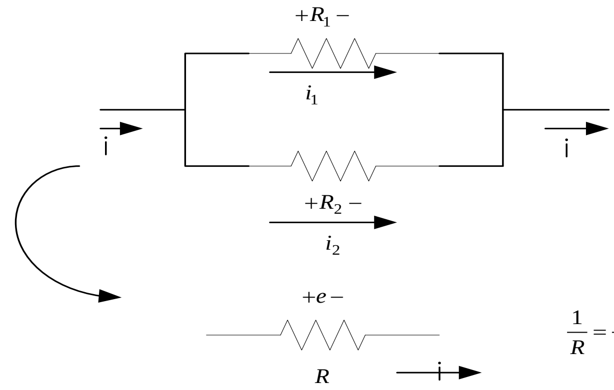


$$e_1 = iR_1, \quad e_2 = iR_2$$

$$e = e_1 + e_2 = i\,(R_1 + R_2)$$

Series/Parallel Capacitance?

- Parallel Resistance



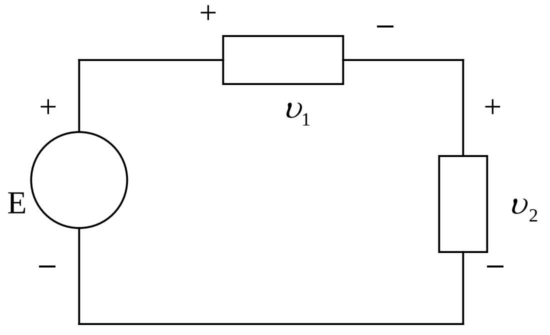
$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$-e_1 + e_2 = 0 \quad \Rightarrow \quad e_1 = e_2$$

$$i = i_1 + i_2 = \frac{e_1}{R_1} + \frac{e_2}{R_2} = e\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \frac{e}{R}$$

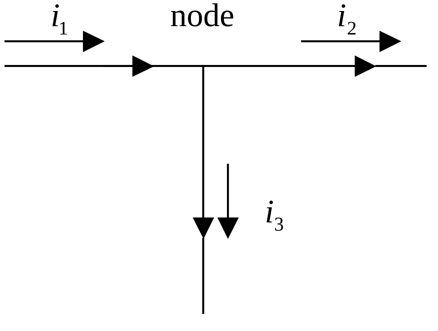
Kirchhoff's laws

1. The algebraic sum of the potential difference around a closed path equals zero.



$$-\upsilon_1 - \upsilon_2 + E = 0$$

2. The algebraic sum of the currents entering (or leaving) a nod is equal to zero.

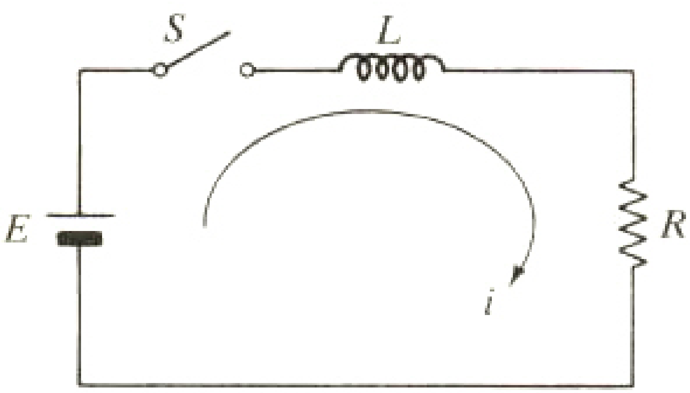


$$i_1 - i_2 - i_3 = 0$$

Current in = Current out

$$\rightarrow \quad i_1 = i_2 + i_3$$

Mathematical Modeling of Electrical Systems



The switch S is closed at t=0

$$E - L\frac{di}{dt} - Ri = 0 \qquad or \qquad L\frac{di}{dt} + Ri = E$$

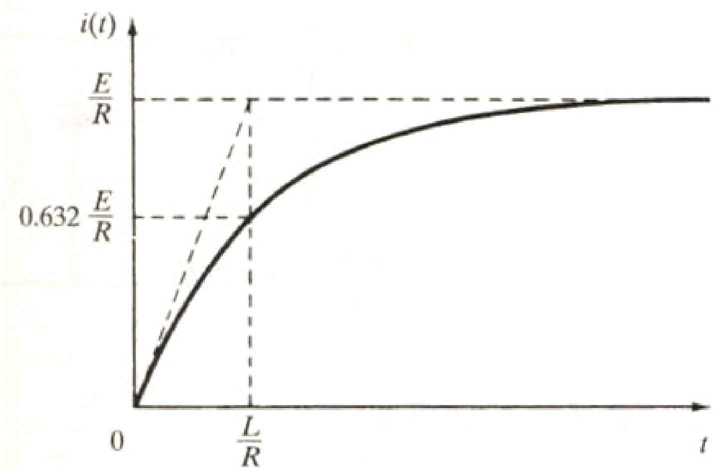
At the instant that switch S is closed, the current $i(0) = 0$

Laplace Transformation : $L\left[sI(s) - i(0)\right] + RI(s) = \dfrac{E}{s}$

$$i(0) = 0 \quad \rightarrow \quad (Ls + R)I(s) = \frac{E}{s}$$

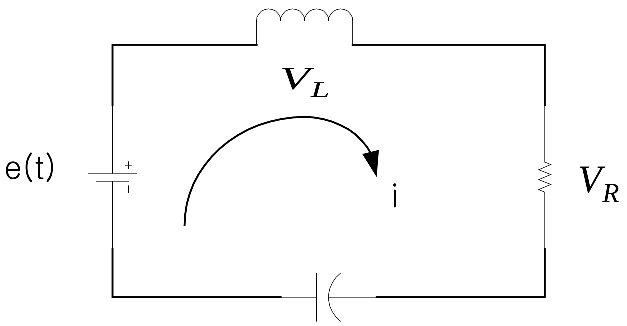
$$I(s) = \frac{E}{s(Ls+R)} = \frac{E}{R}\left[\frac{1}{s} - \frac{1}{s + (R/L)}\right]$$

$$\therefore \; i(t) = \frac{E}{R}\left[1 - e^{-(R/L)t}\right]$$



Examples of Circuit Analysis

ex) R-L-C Circuit



$$-V_L - V_R - V_C + e(t) = 0$$

$$V_L = L\frac{di}{dt}, \quad V_R = iR, \quad V_c = \frac{1}{C}\int i\,dt + V_C(t)$$

$$\frac{dV_c}{dt} = \frac{1}{C}i$$

$$L\frac{di}{dt} + Ri = e(t) - V_C(t)$$

Laplace Transform,

$$(Ls + R + \frac{1}{Cs})I(s) = E(s)$$

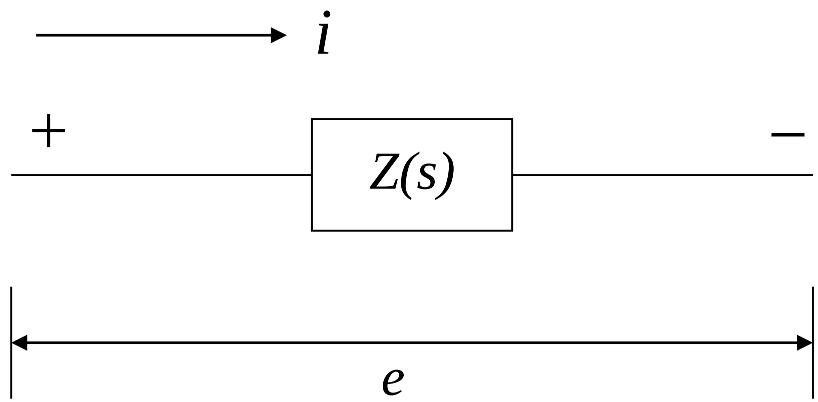
$$\frac{I(s)}{E(s)} = \frac{1}{(Ls + R + \frac{1}{Cs})}$$

$$V_o(s) = \frac{1}{Cs}I(s)$$

$$V_o(s) = \frac{\frac{1}{Cs}}{(Ls + R + \frac{1}{Cs})}E(s) = \frac{1}{(LCs^2 + RCs + 1)}E(s)$$

Step Response?

Complex Impedance

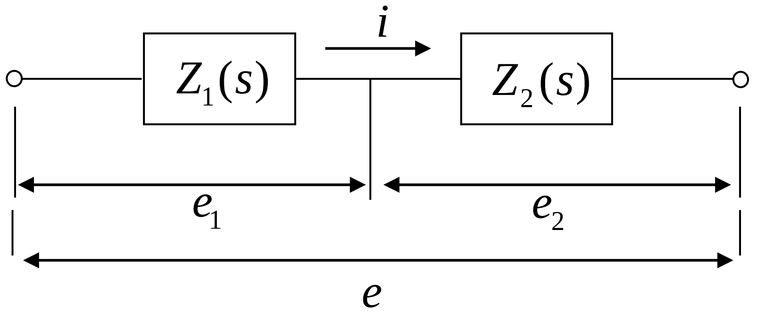


$$I(s) = \frac{E(s)}{Z(s)} \qquad E(s) = Z(s)I(s)$$

Z(s) : complex impedance

Complex Impedance

The complex impedance **Z(s)** of a two-terminal circuit is : the ratio of **E(s)** to **I(s)**



$$Z(s) = \frac{E(s)}{I(s)}, \qquad E(s) = Z(s)I(s)$$

$$E_1(s) = Z_1(s)I(s), \qquad E_2(s) = Z_2(s)I(s)$$

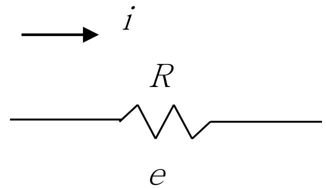
$$\begin{aligned} E(s) &= E_1(s) + E_2(s) \\ &= Z_1(s)I(s) + Z_2(s)I(s) \\ &= \left(Z_1(s) + Z_2(s)\right)I(s) \end{aligned}$$

Direct derivation of transfer function,

without writing differential equations first.

Complex Impedance

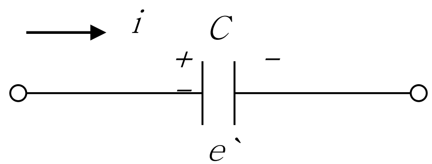
Resistance :



$$e = Ri, \quad E(s) = R\,I(s)$$

$$Z(s) = R$$

Capacitance :

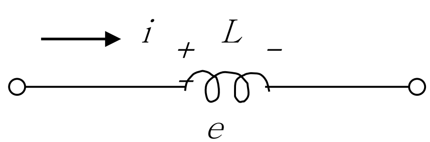


$$\frac{de}{dt} = \frac{1}{C} i$$

$$sE(s) = \frac{1}{C} I(s) \rightarrow E(s) = \frac{1}{Cs} I(s)$$

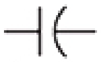
$$\therefore Z(s) = \frac{1}{Cs}$$

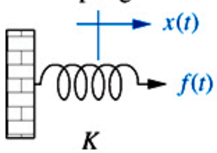
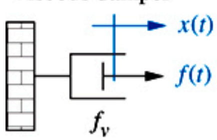
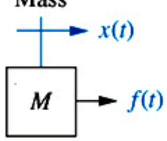
Inductance :



$$e = L\frac{di}{dt}, \qquad E(s) = L\,s\,I(s)$$

$$\therefore Z(s) = Ls$$

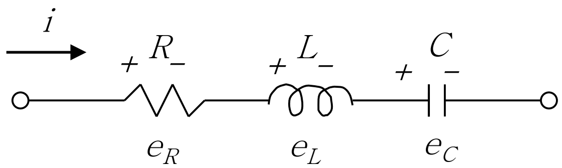
Component	Voltage-current	Current-voltage	Voltage-charge	Impedance $Z(s)=V(s)/I(s)$	Admittance $Y(s)=I(s)/V(s)$
 Capacitor	$v(t)=\frac{1}{C}\int_0^t i(\tau)d\tau$	$i(t)=C\frac{dv(t)}{dt}$	$v(t)=\frac{1}{C}q(t)$	$\frac{1}{Cs}$	Cs
 Resistor	$v(t)=Ri(t)$	$i(t)=\frac{1}{R}v(t)$	$v(t)=R\frac{dq(t)}{dt}$	R	$\frac{1}{R}=G$
 Inductor	$v(t)=L\frac{di(t)}{dt}$	$i(t)=\frac{1}{L}\int_0^t v(\tau)\,d\tau$	$v(t)=L\frac{d^2q(t)}{dt^2}$	Ls	$\frac{1}{Ls}$

Component	Force-velocity	Force-displacement	Impedence $Z_M(s)=F(s)/X(s)$
Spring 	$f(t)=K\int_0^t v(\tau)d\tau$	$f(t)=Kx(t)$	K
Viscous damper 	$f(t)=f_v v(t)$	$f(t)=f_v\frac{dx(t)}{dt}$	$f_v s$
Mass 	$f(t)=M\frac{dv(t)}{dt}$	$f(t)=M\frac{d^2x(t)}{dt^2}$	Ms^2

Examples of Complex Impedance

Series Impedances

ex1)



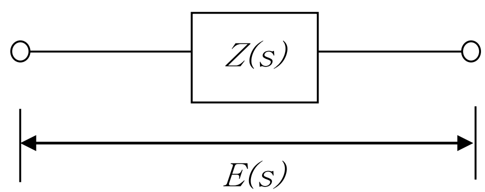
$$e_R = iR, \quad e_L = L\frac{di}{dt}, \quad \frac{de_C}{dt} = \frac{1}{C}i$$

$$e = e_R + e_L + e_C$$

$$E(s) = E_R(s) + E_L(s) + E_C(s)$$

$$= RI(s) + LsI(s) + \frac{1}{cS}I(s)$$

$$= \left(R + Ls + \frac{1}{Cs}\right)I(s)$$

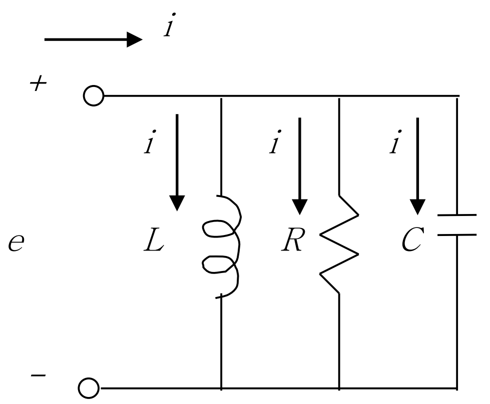


$$\therefore Z(s) = R + Ls + \frac{1}{Cs} = Z_R(s) + Z_L(s) + Z_C(s)$$

Examples of Complex Impedance

Parallel Impedances

ex2)



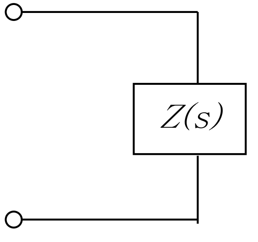
$$i = i_L + i_R + i_C \quad E(s) = Z(s)I(s)$$

$$I(s) = I_L(s) + I_R(s) + I_C(s)$$

$$= \frac{E(s)}{Z_L(s)} + \frac{E(s)}{Z_R(s)} + \frac{E(s)}{Z_C(s)}$$

$$= \left(\frac{1}{Z_L(s)} + \frac{1}{Z_R(s)} + \frac{1}{Z_C(s)} \right) E(s)$$

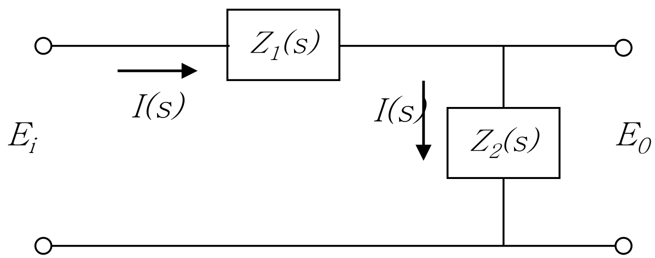
$$= \frac{1}{Z(s)} E(s)$$



$$\therefore Z(s) = \frac{1}{\frac{1}{Z_R(s)} + \frac{1}{Z_L(s)} + \frac{1}{Z_C(s)}} = \frac{1}{\frac{1}{Ls} + \frac{1}{R} + Cs}$$

Examples of Complex Impedance

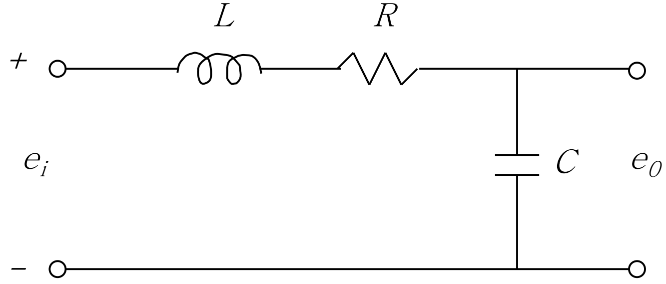
Deriving transfer functions of Electrical circuits by the use of complex impedances.



$$E_i(s) = Z_1(s)I(s) + Z_2(s)I(s)\,, \qquad E_o(s) = Z_2(s)I(s)$$

$$\frac{E_o(s)}{E_i(s)} = \frac{Z_2(s)}{Z_1(s) + Z_2(s)}$$

ex)



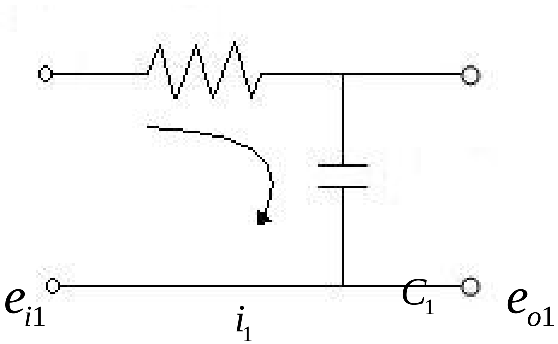
$$\frac{E_o(s)}{E_i(s)} = \frac{Z_2(s)}{Z_1(s) + Z_2(s)}$$

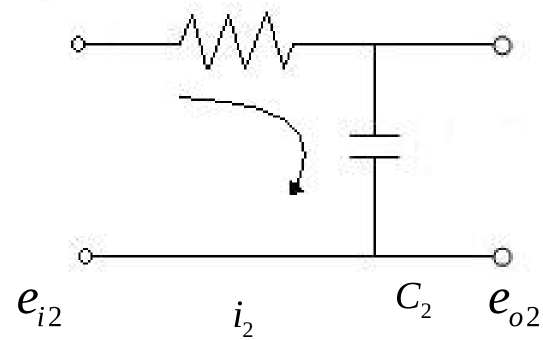
$$Z_1(s) = L\,s + R, \quad Z_2(s) = \frac{1}{Cs}$$

$$\frac{E_o(s)}{E_i(s)} = \frac{\frac{1}{Cs}}{Ls + R + \frac{1}{Cs}} = \frac{1}{LCs^2 + RCs + 1}$$

Transfer Functions of Cascaded Elements

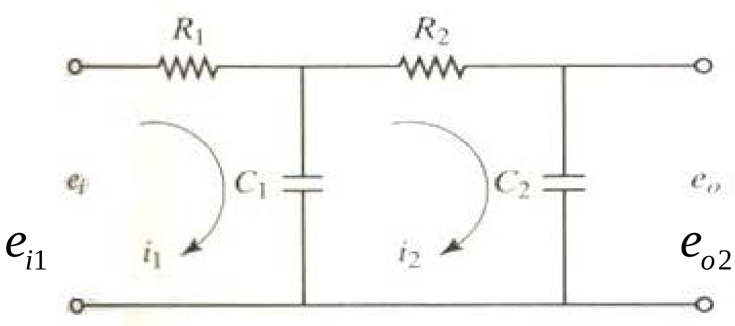
Consider two RC circuits





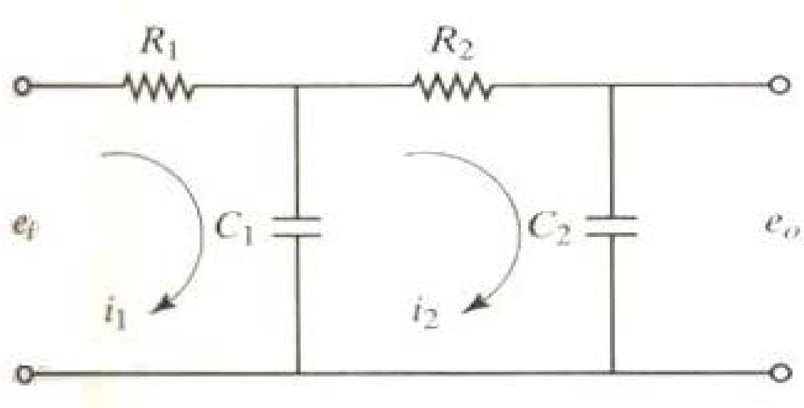
$$\frac{E_{o1}(s)}{E_{i1}(s)} = \frac{1}{R_1C_1s+1} = G_1(s)$$

$$\frac{E_{o2}(s)}{E_{i2}(s)} = \frac{1}{R_2C_2s+1} = G_2(s)$$



$$\frac{E_{o2}(s)}{E_{i1}(s)} = ?$$

Transfer Functions of Cascaded Elements
Loading Effect



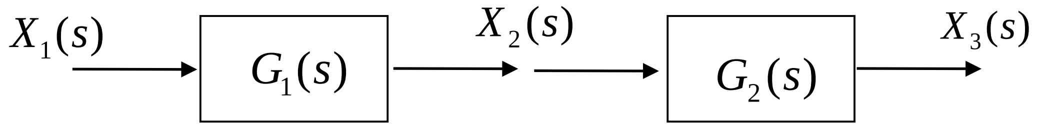
$$E_i(s) = \frac{1}{C_1 s}\left[I_1(s) - I_2(s)\right] + R_1 I_1(s), \quad \frac{1}{C_1 s}\left[I_2(s) - I_1(s)\right] + R_2 I_2(s) + \frac{1}{C_2 s} I_2(s) = 0, \quad E_o(s) = \frac{1}{C_2 s} I_2(s)$$

$$T.F \;:\; \frac{E_o(s)}{E_i(s)} = \frac{1}{(R_1C_1s+1)(R_2C_2s+1)+R_1C_2s} \neq \frac{1}{(R_1C_1s+1)(R_2C_2s+1)}$$

$$\therefore \quad \frac{E_o(s)}{E_i(s)} \neq \frac{E_{o1}(s)}{E_{i1}(s)} \cdot \frac{E_{o2}(s)}{E_{i2}(s)} \longrightarrow$$ **Loading effect**

Transfer Functions of Cascade Elements

Input Impedance, Output Impedance



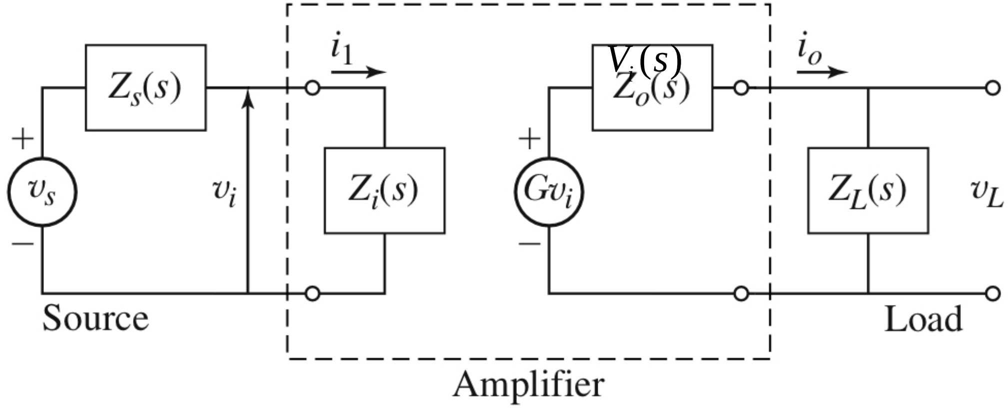
$$G(s)=\frac{X_3(s)}{X_1(s)}=\frac{X_2(s)}{X_1(s)}\cdot\frac{X_3(s)}{X_2(s)}=G_1(s)G_2(s)$$

If the "input Impedance" of the second element is infinite, the output of the first element is not affected by connecting it to the second element.

Then, $G(s)=G_1(s)G_2(s)$

Transfer Functions of Cascade Elements

Isolating Amplifier



This amplifier circuit has to

1. Not affect the behavior of the source circuit.
2. Not be affected by the loading circuit.

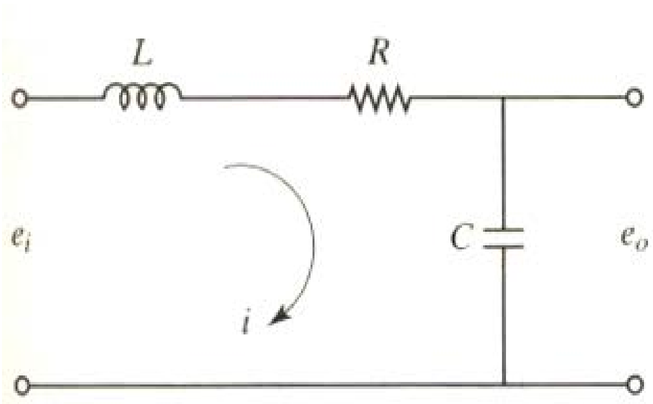
$$V_i(s) = \frac{Z_i(s)}{Z_i(s)+Z_s(s)} V_s(s) \approx V_s(s)$$

This isolating amplifier circuit has to have

1. a very high input impedance,
2. very low output impedance

$$V_L(s) = Z_L(s) I_o(s) = \frac{Z_L(s)}{Z_o(s)+Z_L(s)} G V_o(s) \approx G V_o(s)$$

State-Space Mathematical Modeling of Electrical Systems



By Kirchhoff's voltage law

$$L\frac{di}{dt} + Ri + v_c = e_i\,, \qquad \frac{dv_c}{dt} = \frac{1}{C}i, \qquad e_o = v_c$$

Assume, initial condition is 0,

$$LsI(s) + RI(s) + V_c(s) = E_i(s), \qquad V_c(s) = \frac{1}{Cs}I(s)$$

$$T.F \;:\; \frac{E_o(s)}{E_i(s)} = \frac{1}{LCs^2 + RCs + 1}$$

State-Space Mathematical Modeling of Electrical Systems

Differential equation : $\ddot{e}_o + \frac{R}{L}\dot{e}_o + \frac{1}{LC}e_o = \frac{1}{LC}e_i$

State variable : $x_1 = e_o\,, \quad x_2 = \dot{e}_o$

Input and output : $u = e_i\,, \quad y = e_o = x_1$

State-space equation :

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\frac{1}{LC} & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{LC} \end{bmatrix} u, \quad y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

End of lecture 6-1