Future EV World with Choco-choco Charge

Yoichi Hori

University of Tokyo

ちょこちょこ充電！

My Talk Today

(1) **We can not stop a big flow to electrification.**

(2) **Future Vehicles will be linked to power network.**

- 500 km range vehicles are non-sence.
- Towards Choco-choco charge vehicle like trains.
- From batteries to capacitors.
- Wireless power transfer will be important.

(3) Is FCV the final target?

Smaller FCVs should be designed for short range.

(4) **Meaning of Plug-in HEV.**

PHEV will develop a big market of Pure-EV.

(5) **If vehicles will run by electricity, the next topic is motion control.**

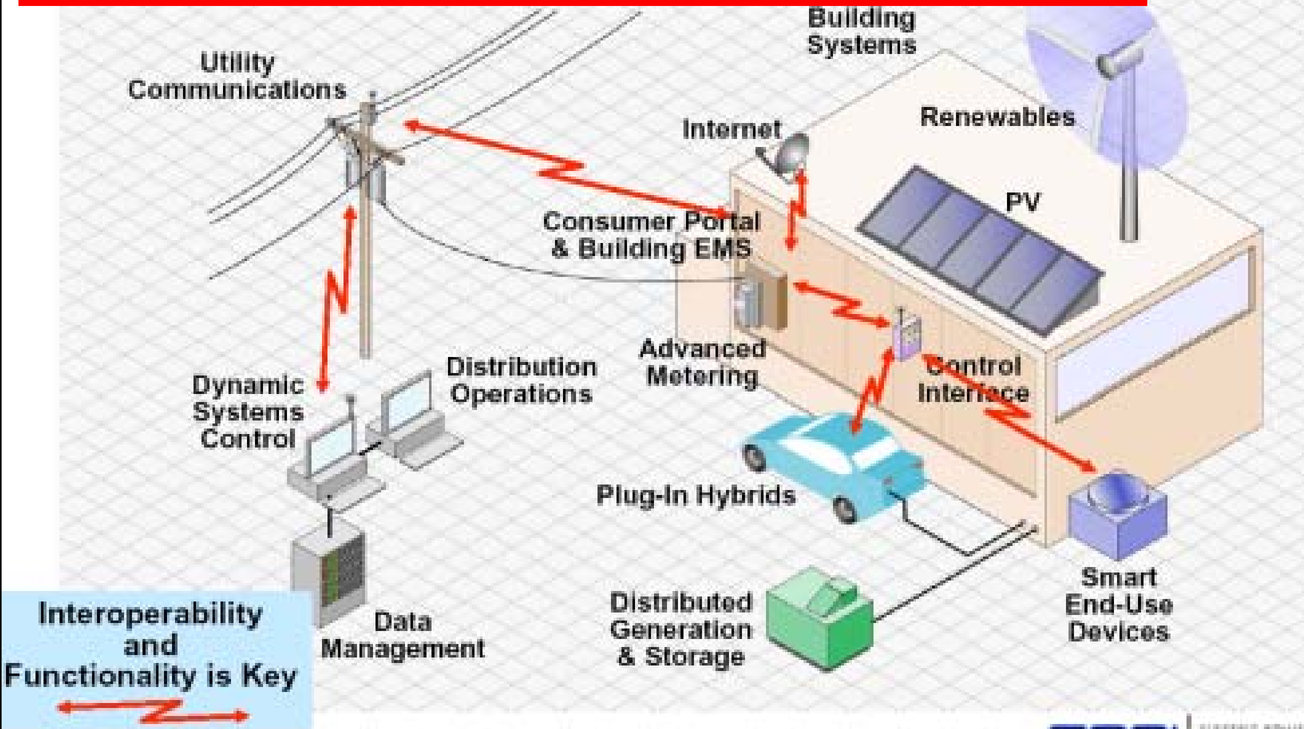
Meaning of Plug-in Hybrid Vehicle

Gasoline Vehicle
→Hybrid Vehicle
→Plug-in Hybrid Vehicle
→Electric Vehicle
Big Flow!

エンジン（排気量、最高出力）	1,496cc　５６kW（76PS）/5,000rpm
モーター（最高出力）	50kW(68PS)/1,200～1,540rpm
EV走行可能最高速度	１００km/h
２次電池（種類、容量）	ニッケル水素電池、6.5×2Ah(13Ah)
EV走行可能距離	13km(10･15モード走行)
充電電源	家庭用電源
充電時間	1～1.5時間(200V)、3～4時間(100V)

Future Intelligent Infrastructure Enabling PHEV and Consumer Choice

Future cars will be linked to power system.



We are seeking new levels of cooperation and new relationships between all stakeh

Electric Power Company

+

Car maker

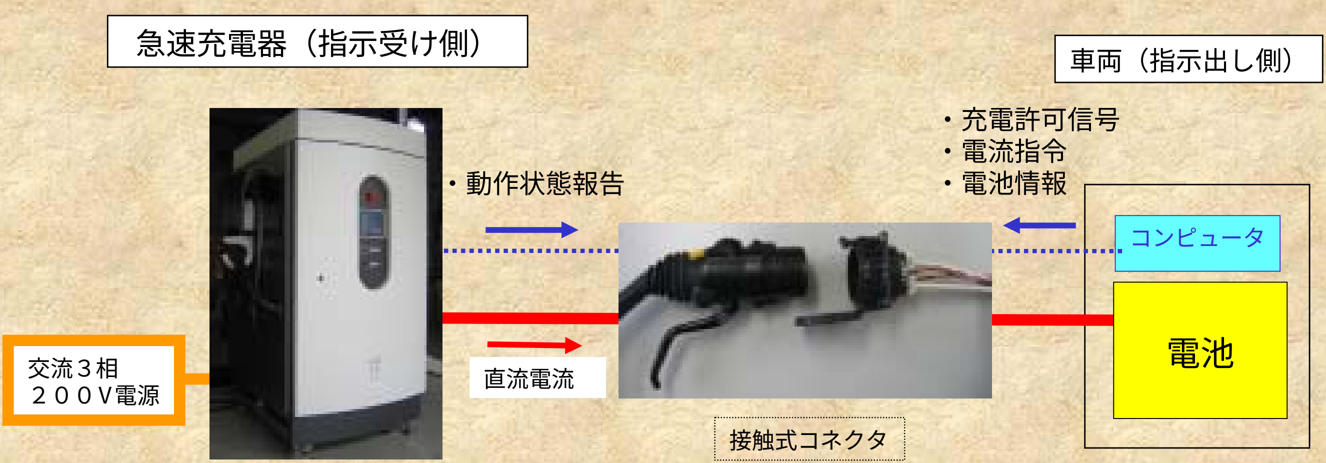
+

Energy Storage Maker

Potential 3rd Parties

- Utilities
- Suppliers
- Battery Manufacturers
- Research
- Policy Makers
- Others

Quick Charger for Various kinds of EVs (TEPCO)

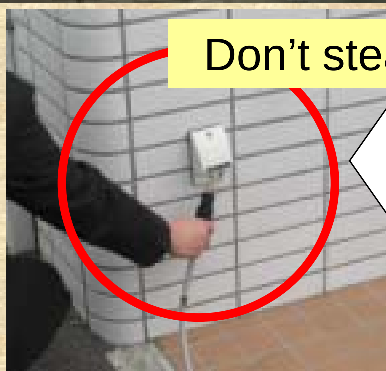


- 5分で４０ｋｍ、１５分で６０ｋｍ走行分の充電が可能
- 車両の指令に従って動作するので自動車メーカー各社の多様な車両に充電可能

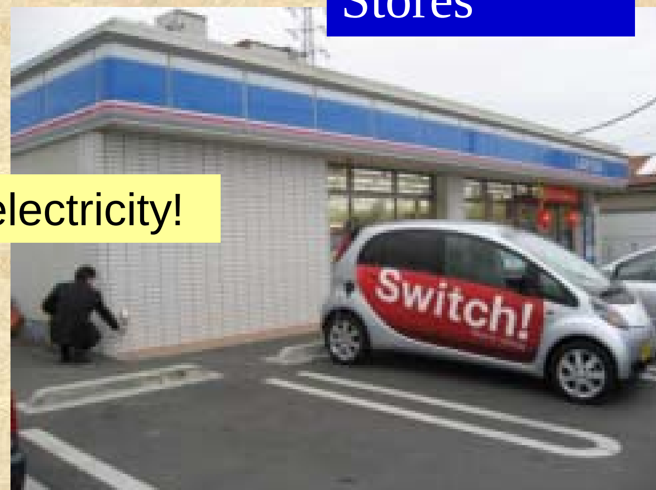
Actually, electric consents are anywhere.

Shopping Mall

Convenience Stores



Don’t steal electricity!



C-COMS 1

NISSHINBO

JRC 日本無線

C-COMS 2

Power Systems

Capacitors of C-COMS

module

cell

1cell (3.0V, 1000F) ×5 series = 1 module

3 parallel and 7 series of 21 modules

Q1: What are the total capacitance and voltage ?

Capacitor-cells "L4"

Non Acetonitrile, AC Carbon-carbon 6.5 Wh/kg, 5.9 kW/kg, 2 ΩF

Power Systems

Capacitor-modules

6, 12, 22-cell

Capacitor changes our Lifestyle ?

Car makers' principle is strange.

「Anytime, Anybody, Anywhere」 → **500km Range Car !!**
(We are forced to buy cars which can run on Sahara Desert. I will never be there.)

Future vehilces will be connected to (Electric) Power System:

(V2H, V2G, G2V ...... ???)

* Energy storage and supply to moving objects are most exciting topic.
* Very quick charge less than 30 seconds.
* 90% charged energy is available.
* Remaining energy is easily known. (dependable!)

→ Small energy storage is OK. 50km range is enough.
→ True "my car" will be ordered like DELL Computer.

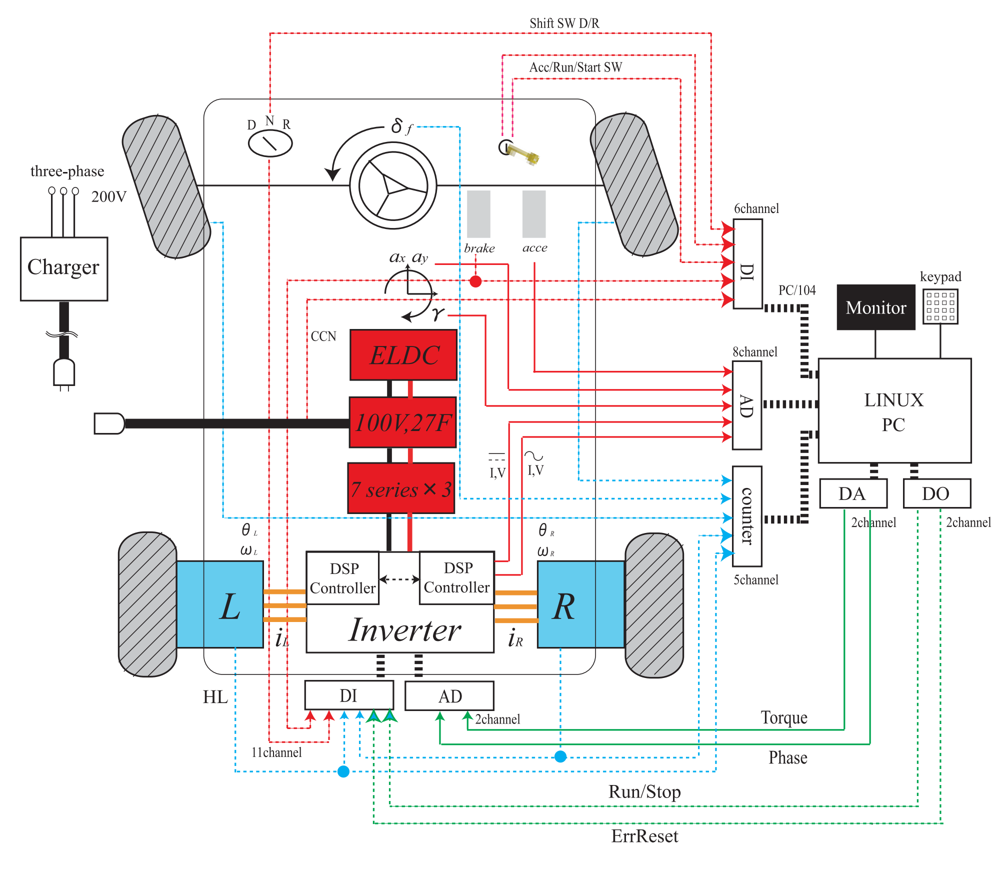
Small Capacitor Vehicle C-COMS

COMS3
(battery driven)
(universal usage)

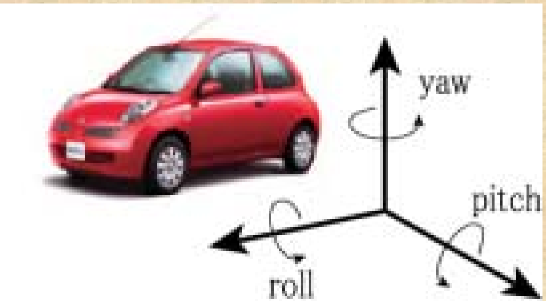
C-COMS1
(capacitor driven)
(special inverter)

C-COMS2
(capacitor driven)
(DD inwheel motor)

Control System Configuration of C-COMS1



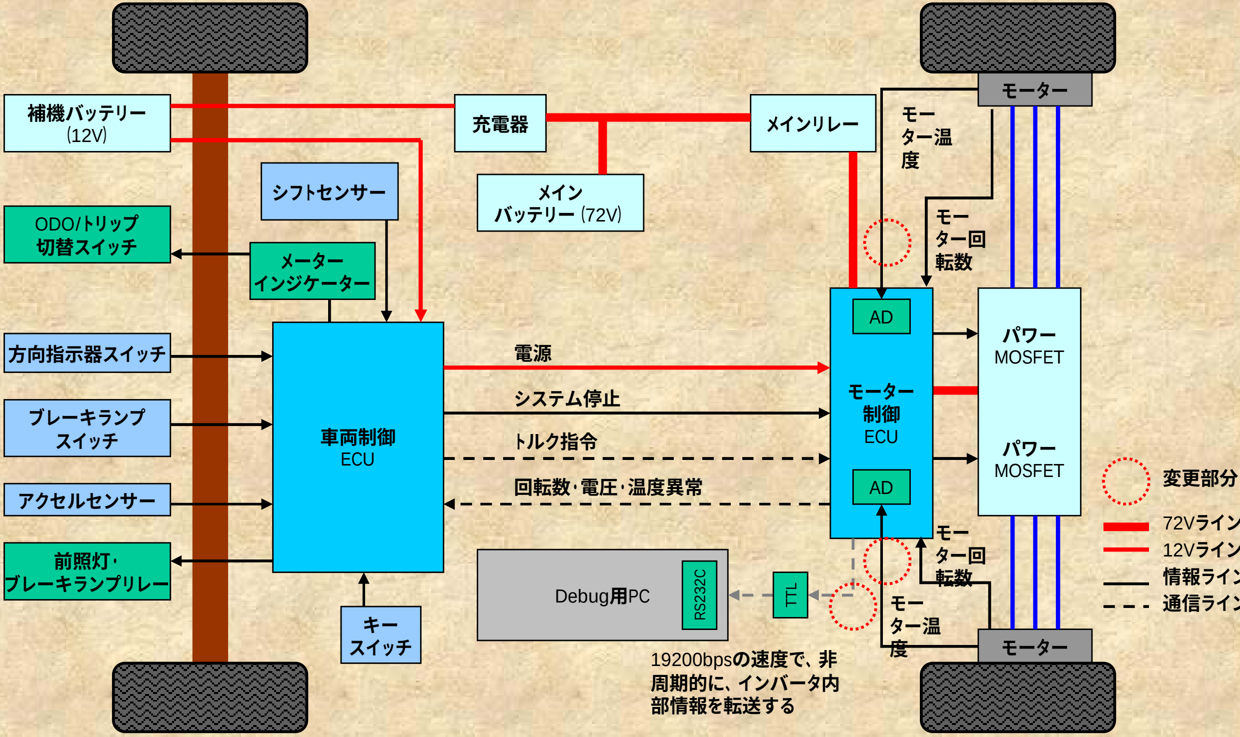
Motion Control planned by using C-COMS



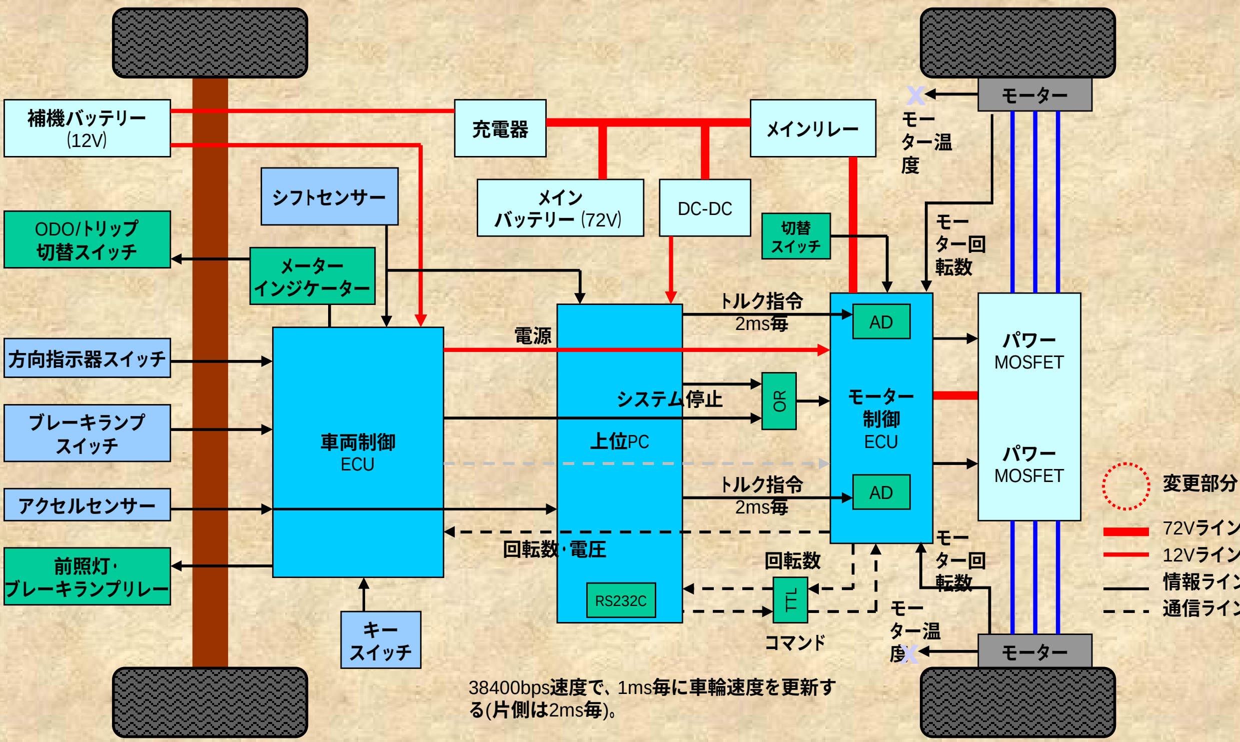
(1) TCS (traction control) based on MFC
(2) Slip prevention using Back-EMF Observer
(3) Hybrid ABS and TCS
(4) Adhesion Control emulating Separately Excited DC Motor's Property
(5) Estimation and Control of Body Slip Angle β
(6) DYC based on Yaw Moment Observer
(7) Estimation of μ Gradient and Peak μ Estimation using Brush Model and Driving Force Observer"
(8) Realtime Speed Pattern Generator to Improve Ride-comfort using Driver's Will Estimation
(9) Driving Force Distribution Control based on Estimation of Side Force


secret DD motor!!

COMS3 Control System
-BEFORE-



COMS3 Control System
-AFTER-



Old charger
20min drive needs
150sec charging(30A)

New charger
20min drive needs
30sec charging(150A)

electric charge: $Q=CV=IT$, $Q=C\Delta V=I\Delta T$

100[F]X50[V]=150[A]X30[s]

Capacitor is "Can of Energy and Wisdom"

Advantage of Super-capacitor

(1) Long Life （「Physical Battery」 without chemical reaction）
(2) Large Current Charge/Discharge （… 30 second charge）
(3) Remaining Energy can be known from Terminal Voltage
(4) Environment Friendly without heavy metal usage

Key points to be solved

(1) Electronic circuit is the key to make cell voltage balance.
(2) Demerit is only low energy density

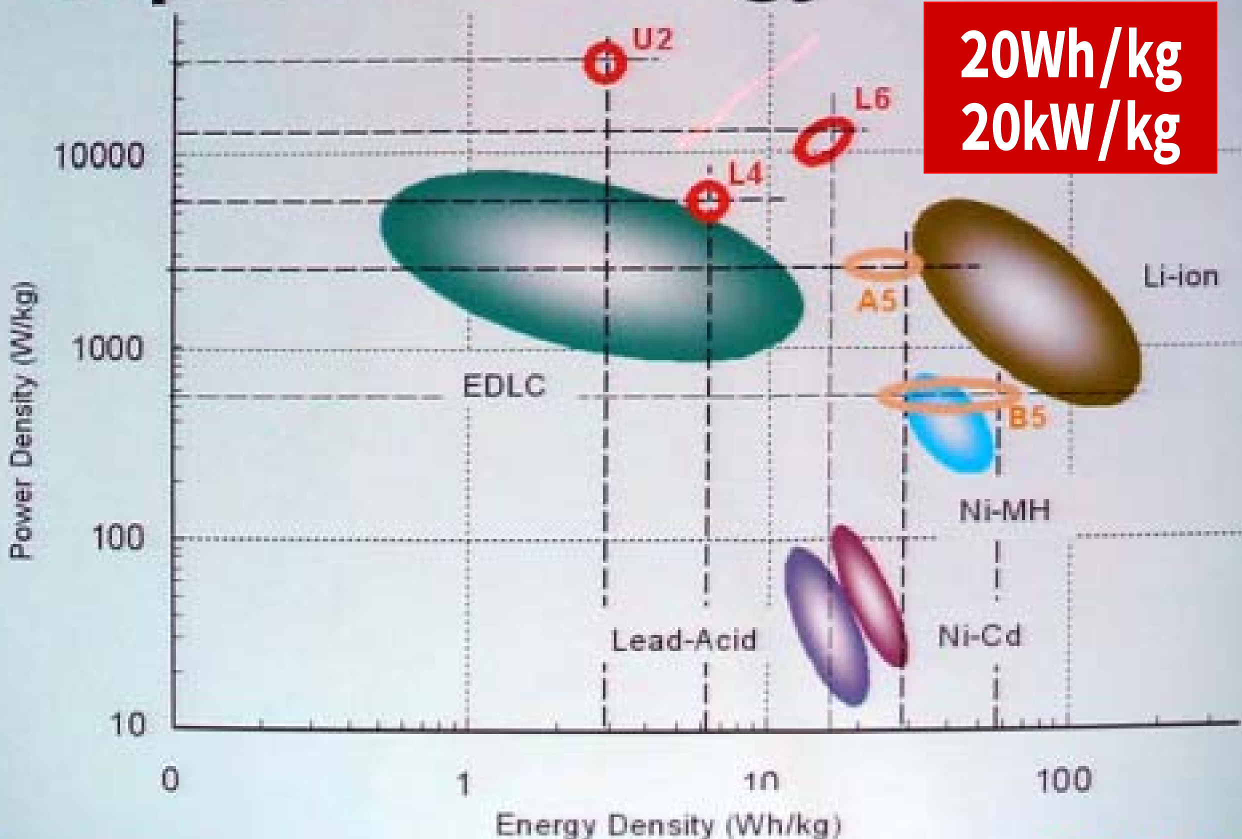
…. Nano-gate capacitor (NGC) can solve this problem.

But, present status may be enough.

If we can use 30～100V, 90% of charged energy is available.

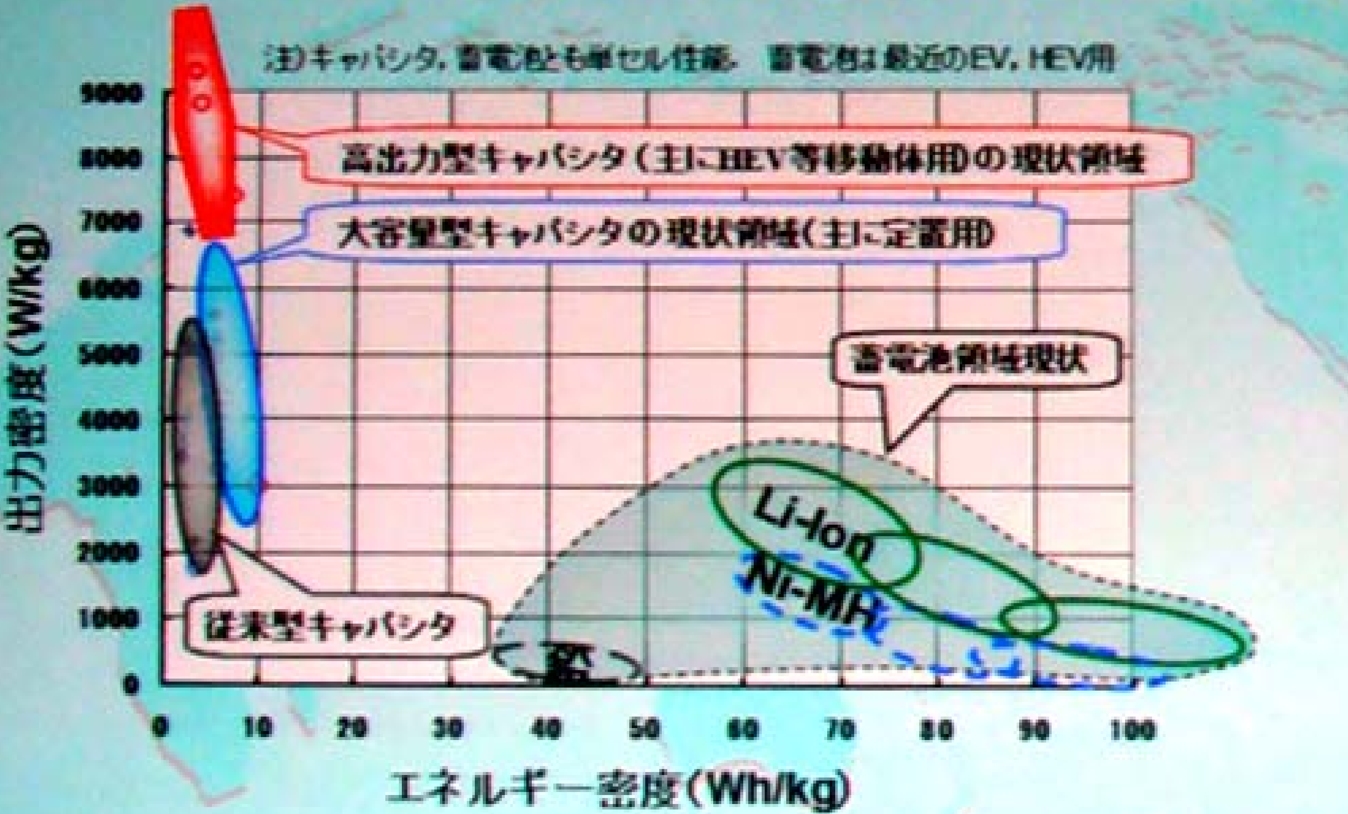
Chairman of "Capacitors Forum"

Capacitor's Energy & Power

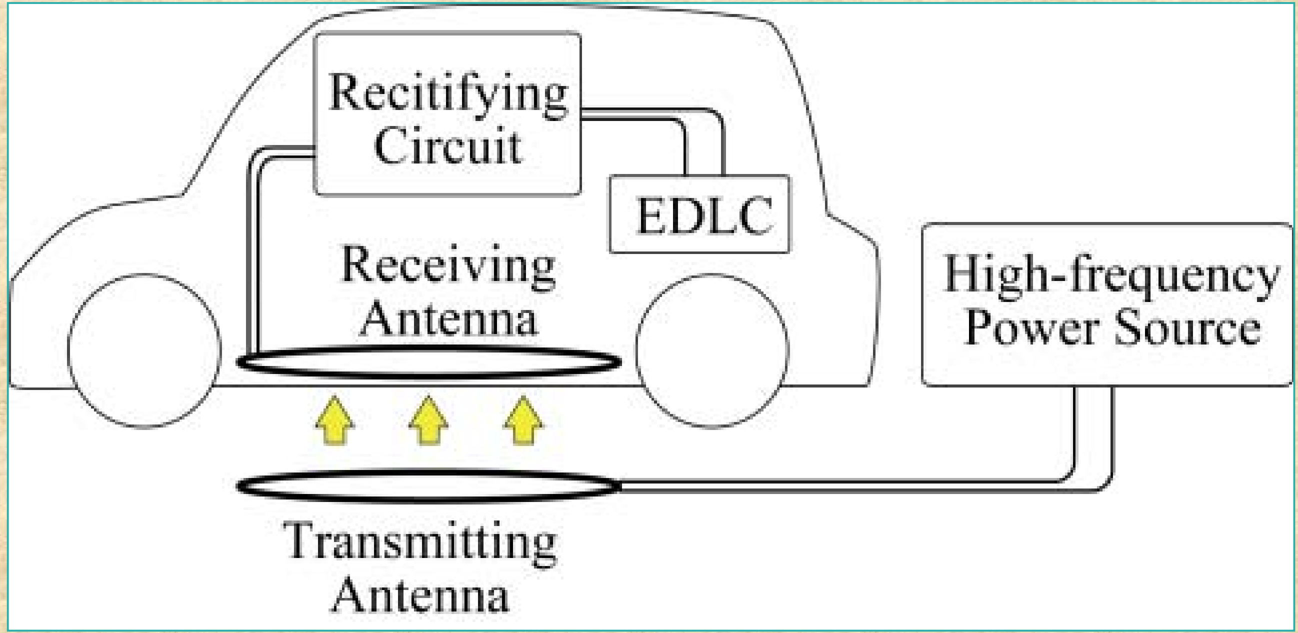


キャパシタの可能性と課題調査 その1

キャパシタと蓄電池の性能比較




5106 8666
上海玫瑰女子医



Wireless Power Transfer

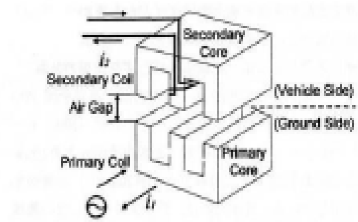
→ Plug-in-less Hybrid Vehicle ….

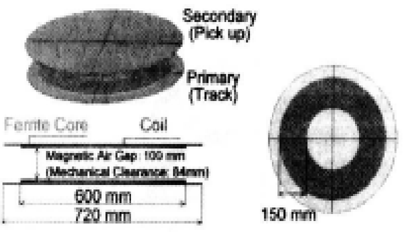
Bad ①Electromagnetic induction: Gap is 20cm. Displacement is very small.

Bad ②Microwave power transition: Very long distance, low efficiency

Excellent ③Electromagnetic resonant coupling (WiTricity): Gap is a few meter.

①

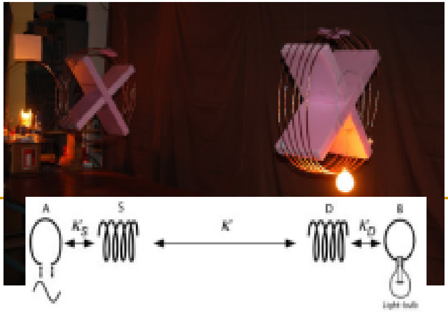




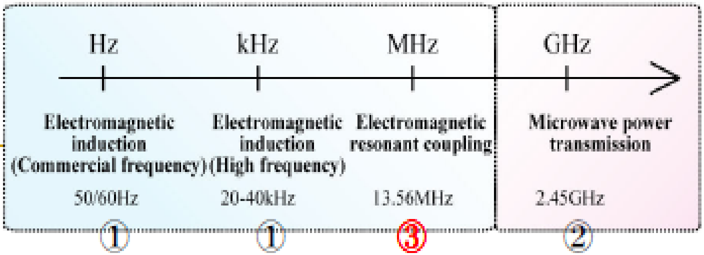
②

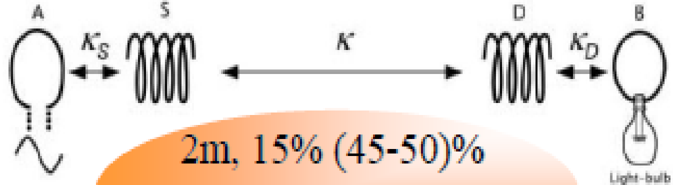
		Gap	Efficiency	Displacement	Power
①	Electromagnetic indction (50, 60Hz)	Bad	Excellent, bad	Bad	Excellent
	Electromagnetic indction (kHz)	Good	Excellent	fair	Excellent
②	Maicrowave power transmission (GHz)	Excellent, bad	fair	fair	fair
③	Electromagnetic resonant coupling (MHz)	**Excellent**	**Excellent**	**Excellent**	**Excellent**

③



Non-radiative energy **Radiative energy**





2m, 15% (45-50)%

(less 1m, over 90%)

Advantage of Electric Vehicle

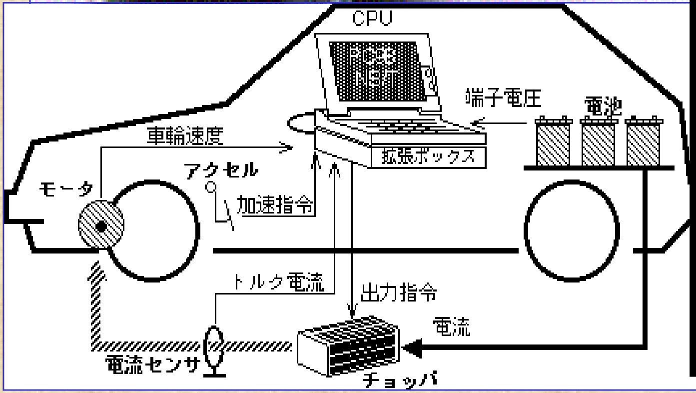
= Advantage of Electric Motor：CONTROL

- ■Quick Torque Response
  - → Anti-Slip Control, Skid Detection
- ■Distributed Motor Installation
  - → Vehicle Dynamics Control
- ■Measurable Torque
  - → Road Condition Estimation

Electric Vehicles in Hori Lab.

UOT March Ⅰ

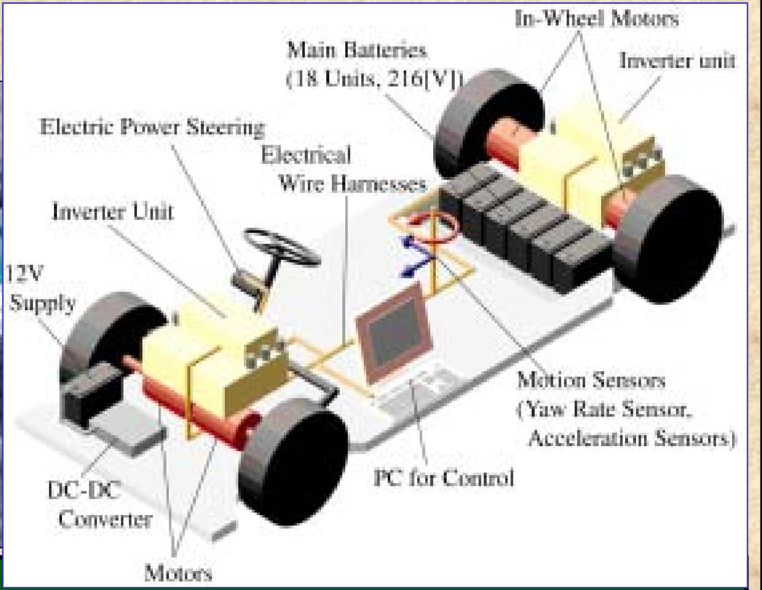
Motor	Advanced DC, FB1-4001 (Series Wounded)
Rated Power	32.5[kW]/44.3[HP]
Battery	Lead Acid, 120V
Chassis	Nissan March Micra
CPU	i386SL, 20[MHz]



- Completed in 1996.
- One DC motor is used. No regenerative brake.
- Wheel speeds in front and rear are measured.
- Digital control by Note PC.

Electric Vehicles in Hori Lab.

UOT March Ⅱ

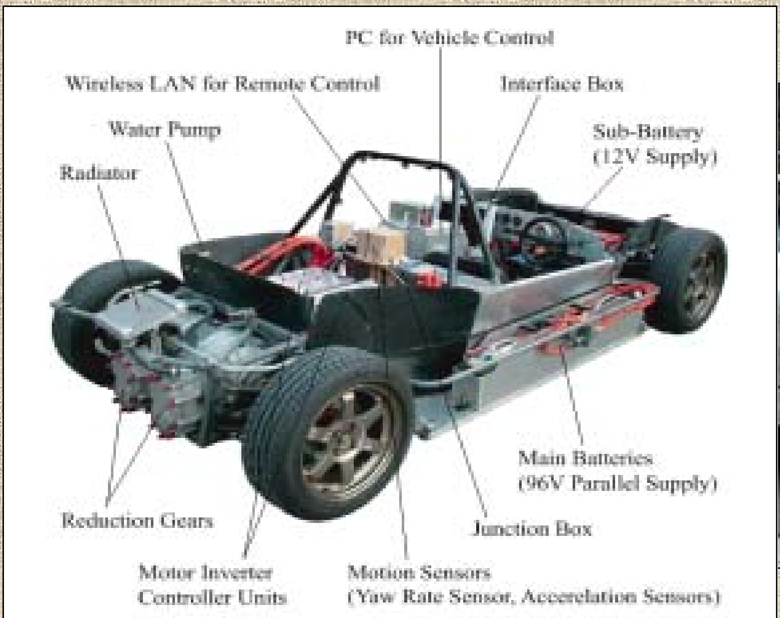


- Completed in 2001.
- 4 in-wheel motors are used.
- Independent torque control of each wheel is possible.
- Regenerative brake is OK.
- Speed of 4 wheel, yaw rate, and acceleration are measured.

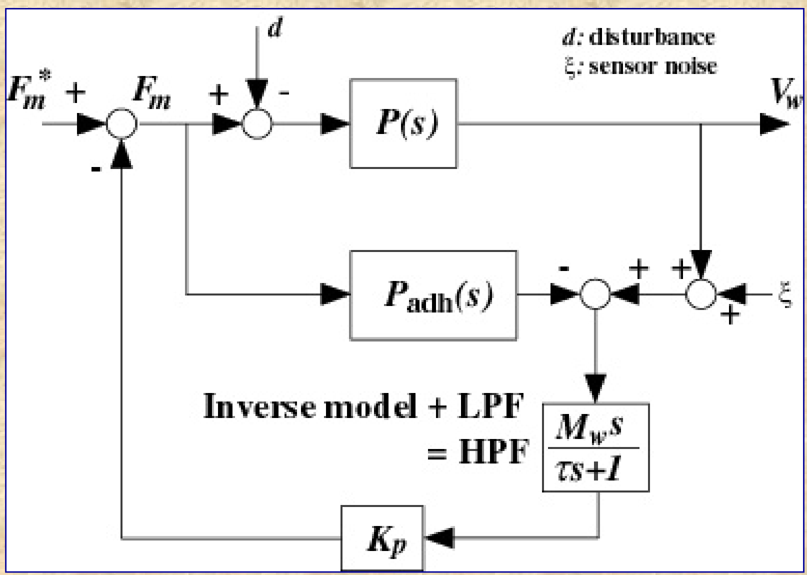
Electric Vehicles in Hori Lab.

UOT Cadwell EV

Adhesion Control based on Torque Reduction Characteristics of Separately-wound DCM → Realization using IPM Motor



MFC: Model Following Control



Transfer Function from F_m^* to V_w

$$\frac{V_w}{F_m^*} = \frac{1}{1+\frac{K_p M}{M+M_w}} \frac{1}{M_w s}$$

(1) Adhesive Wheel

$$P(s) = P_{adh}(s)$$

Controller does **nothing** for adhesive wheel.

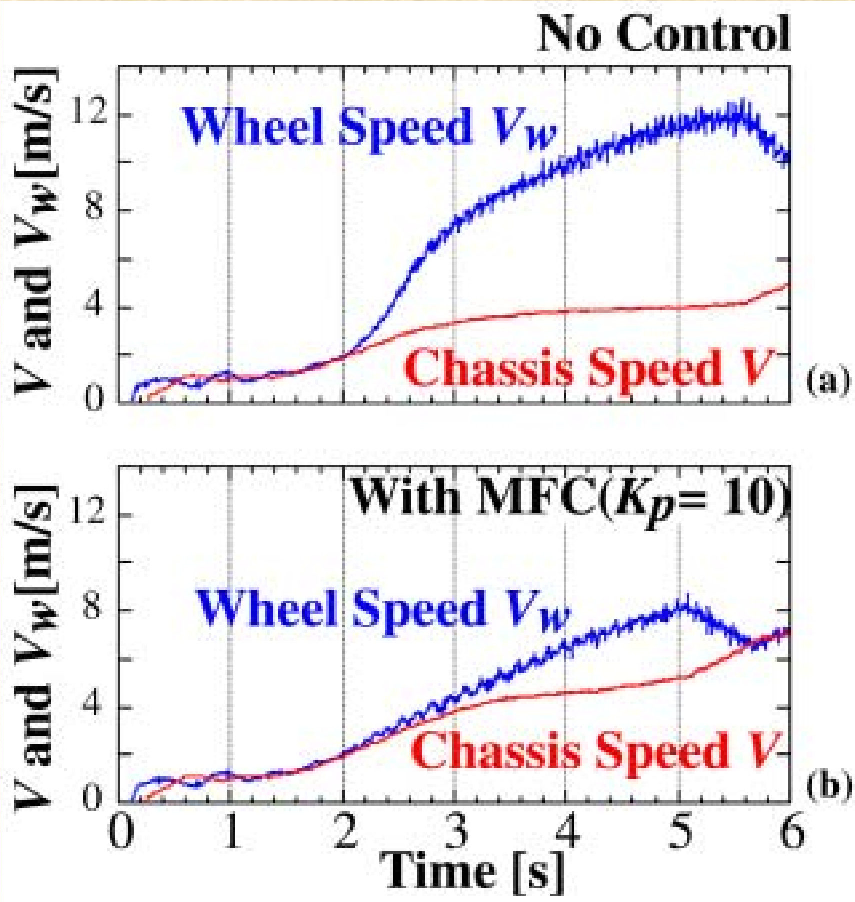
(2) Skidding Wheel

$$P(s) = P_{skid}(s)$$

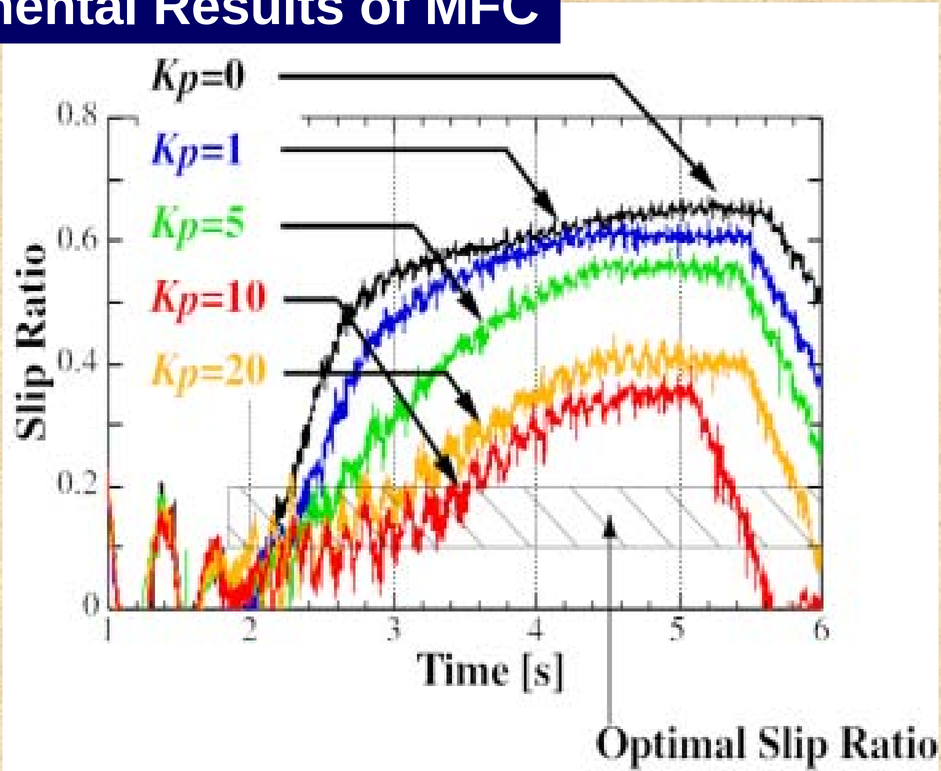
$$\frac{V_w}{F_m^*} = P_{adh}(s)$$

Experiment on Anti-slip Control

Results of Anti-slip Control



Experimental Results of MFC



Mechanical characteristic can be changed by electrical control !

Experiment on Hybrid ABS

With Control

Without Control

Breaking distance becomes much shorter.

Vehicle Dynamics Model

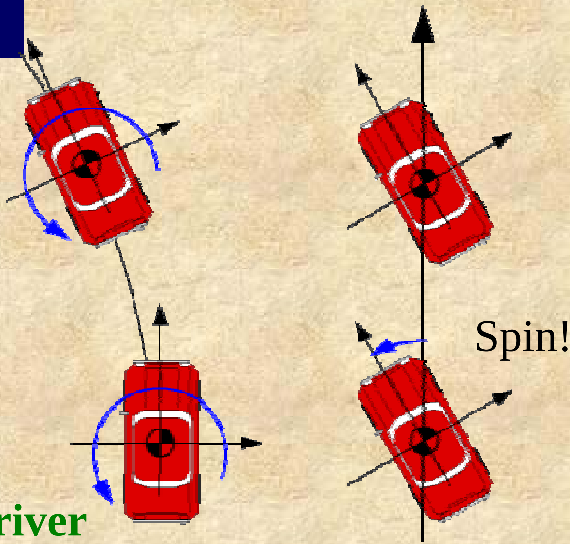
【Bicycle Model】

$$\dot{x} = Ax + B\delta_f, \qquad x = \begin{bmatrix} \beta \\ \gamma \end{bmatrix}$$

$$A = \begin{bmatrix} -2\dfrac{C_f + C_r}{mV} & -1-2\dfrac{l_f C_f - l_r C_r}{mV^2} \\ -2\dfrac{l_f C_f - l_r C_r}{I} & -2\dfrac{l_f^2 C_f - l_r^2 C_r}{IV} \end{bmatrix},$$

$$B = \begin{bmatrix} \dfrac{2C_f}{mV}, \dfrac{2C_f}{I} \end{bmatrix}^t$$

δ_f ：**Steering Angle of Driver**



yaw rate γ　　**slip angle β**

【Vehicle Motion Control】

■ β stabilization → prevention of spin and side slip

⇒**VSC (Vehicle Stability Control)**

■ Linearization of γ / δ_f → drivability

⇒**DYC (Direct Yaw Moment Control)**

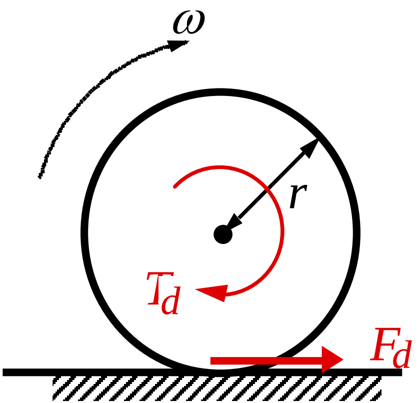
Cornering Experiment

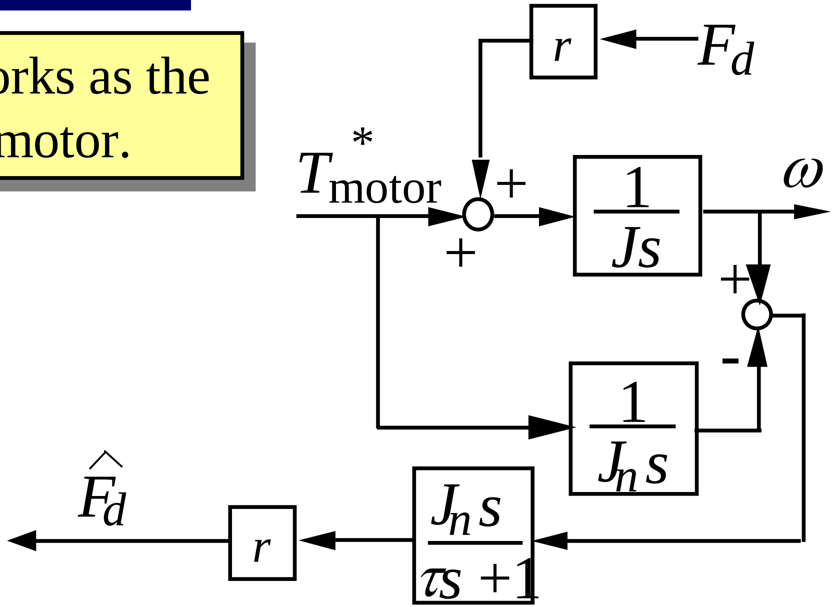
Without Control
(Rear wheel locked and the driver tried to stabilize the motion.)

With Control
(Vehicle succeeded in stable cornering.)

Driving Force Observer

Driving force F_d works as the disturbance for the motor.

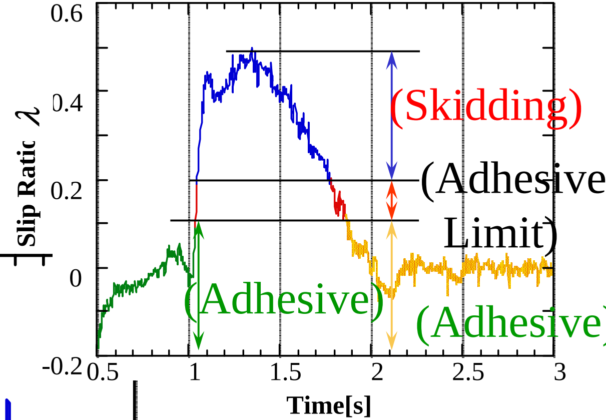


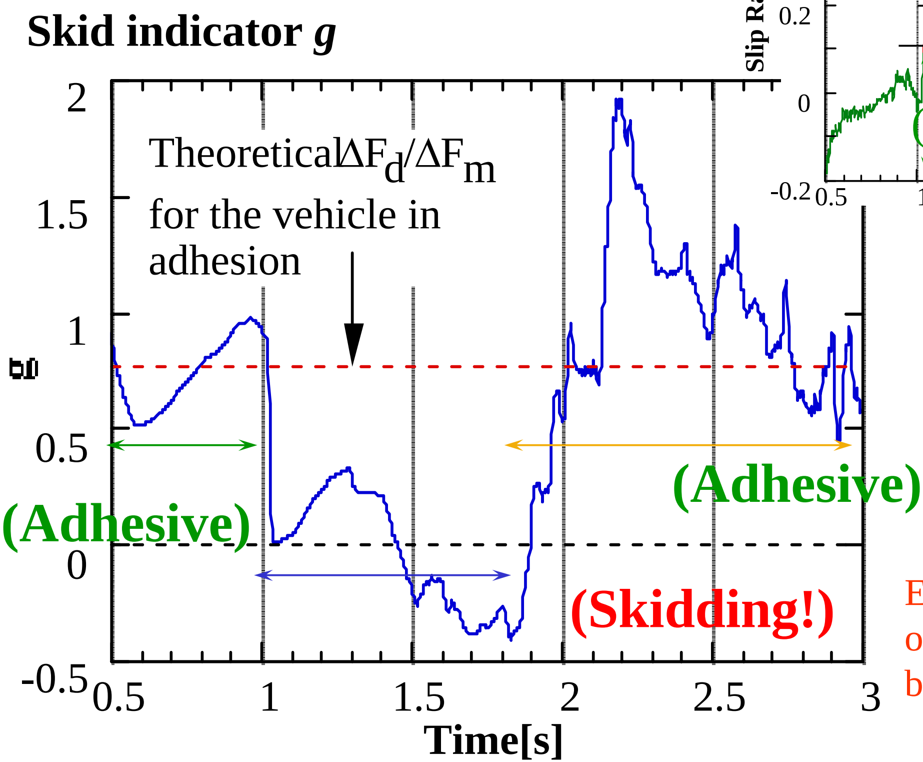


Disturbance observer can estimate the load torque $\boldsymbol{F_d}$.
because the motor torque is easily known.

→ **Driving Force Observer**

Result of the Skid Detection

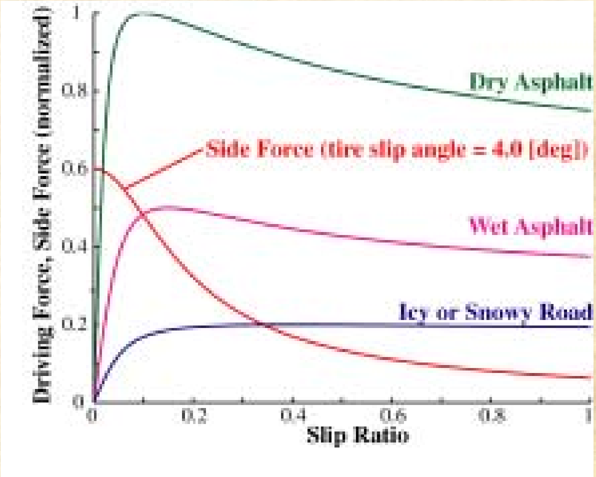




Monitor using non-driving wheel.

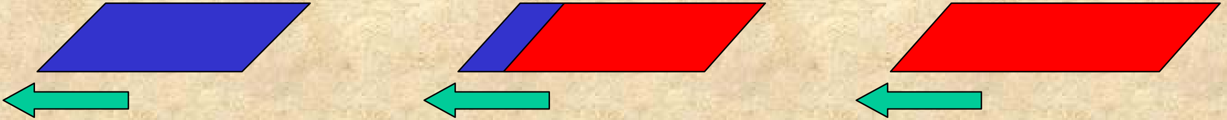
Estimation of the gradient of characteristic of F_m-F_d by RLS method.

Yamazaki Method



Estimation of the peak from the behavior around $\boldsymbol{\lambda}=0$.

Static friction　Viscosity friction

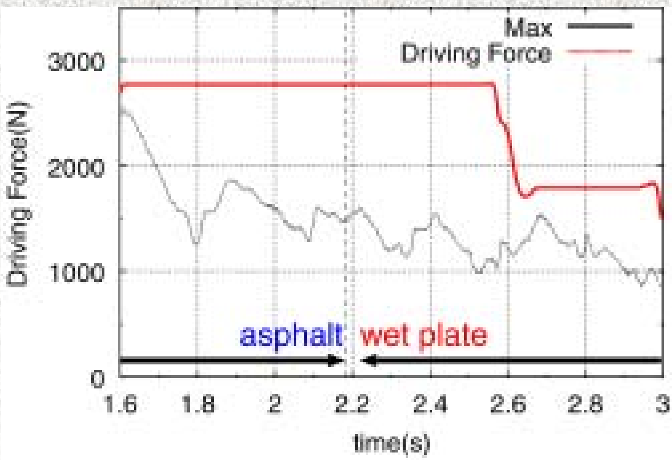


$\lambda \approx 0$　　Before the peak-$\boldsymbol{\mu}$　　After the peak-$\boldsymbol{\mu}$

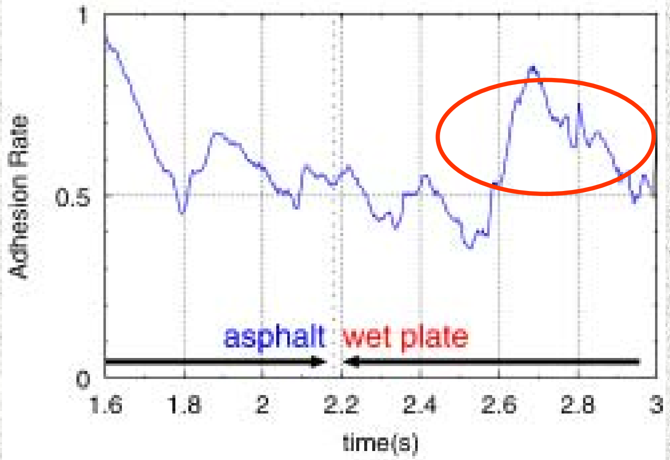
This red part includes the information of the peak-$\boldsymbol{\mu}$!

Experimental Result of Road Condition Estimation

<u>dry asphalt road→ wet plate</u>



estimate of peak- **μ**



driving force /maximum driving force

The car tells the driver,
"We have entered snowy road".

Necessity of Estimation and Control of Body Slip Angle β

Fig.5 noncontact optical sensor to measure β

If body slip angle is too big, EVs cannot be controlled (spin off). **β** should be controlled. But **β** is difficult to measure because expensive and big size sensor like Fig. 5 is needed.

Proposed β Observer

$$\dot{\hat{x}} = A\hat{x} + Bu - K(\hat{y} - y)$$
$$\hat{y} = C\hat{x} + Du$$

Linear observer

y **is measurable signal.**

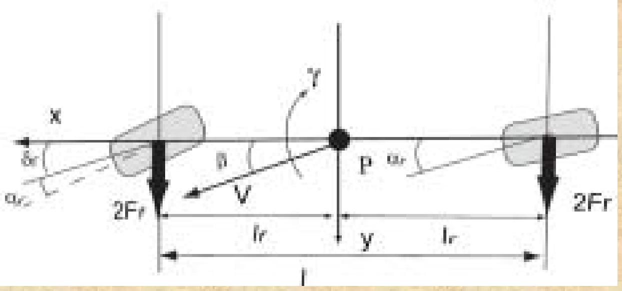
We utilize lateral acceleration *ay* and yaw rate γ, which are must be reconstructed.

Matrix gain *K* changes observer's characteristic

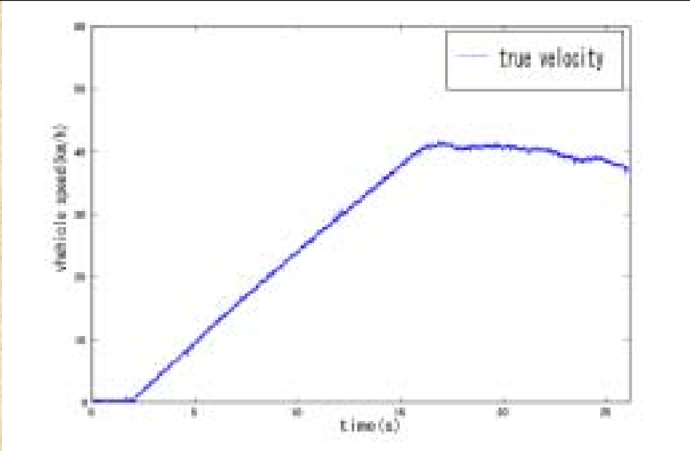
$$A = \begin{bmatrix} \frac{-(C_{fl}+C_{fr}+C_{rr}+C_{rl})}{mv} & \frac{-l_f(C_{fl}+C_{fr})+l_r(C_{rl}+C_{rr})}{mv^2} - 1 \\ \frac{-(l_f(C_{fl}+C_{fr})+l_r(C_{rl}+C_{rr}))}{I} & \frac{-l_f^2(C_{fl}+C_{fr})-l_r^2(C_{rl}+C_{rr})}{Iv} \end{bmatrix}$$

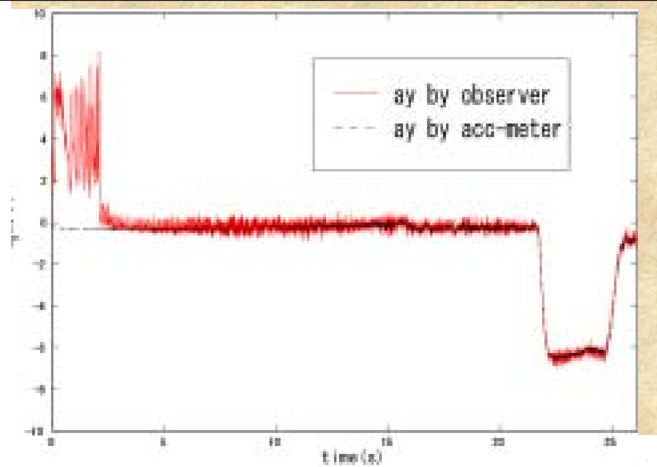
$$B = \begin{bmatrix} \frac{C_{fl}+C_{fr}}{mv} & 0 \\ \frac{l_f(C_{fl}+C_{fr})}{I} & \frac{1}{I} \end{bmatrix}$$

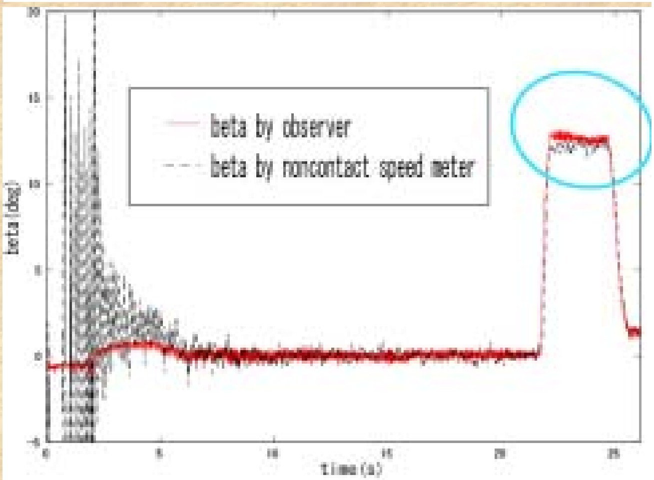
$$x = \begin{bmatrix} \beta \\ \gamma \end{bmatrix}, \quad u = \begin{bmatrix} \delta_f \\ N \end{bmatrix}$$

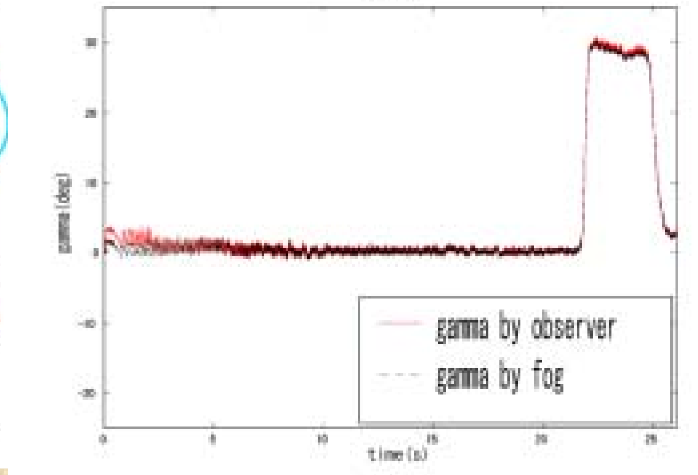


Two wheel model

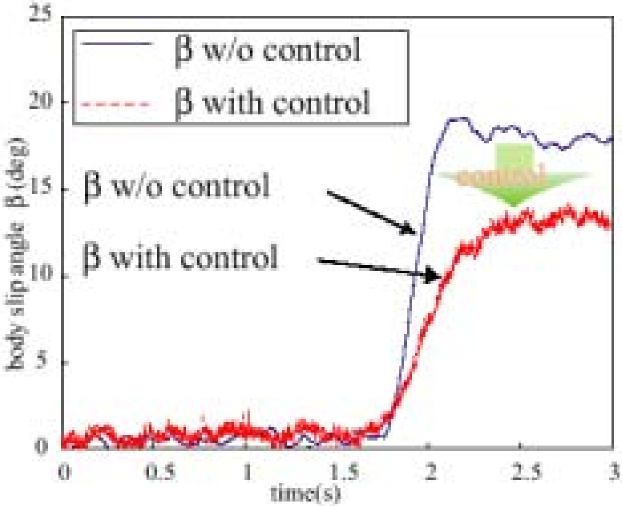




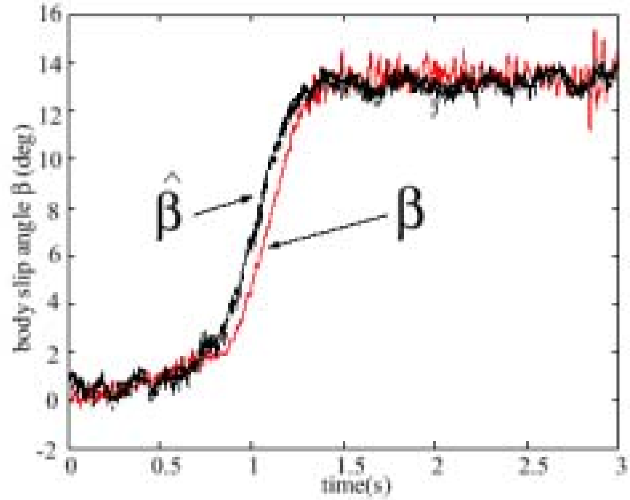




β Estimation in Non-linear Region



(a-1)Comparison between β with normal and the proposed control



(a-2)measured value and estimation of β

β Control in Non-linear Region

CONCLUSION

Electric Motor's Advantage：

- ■Torque response is quick and accurate.
- ■2~4 in-wheel motors can be installed.
- ■Generated torque is easily known.

- **Future vehicle must run by <u>electricity</u> and may run by <u>capacitor</u>.**
- **If so, "CONTROL" is the most exciting and important topic.**

Ladies and Gentlemen!

Change your cars to super-capacitor driven small EVs as these for our future!

Let’s go to the heaven by small cars.