# Short Summer Training for KMUTT student on 2009 October and November in UEC

**Period**: 4 weeks between 2009 October 18th and November 13th.

**Location** : UEC Department of Electronic Engg., 1-5-1, Chofu, Tokyo 182-8585 Japan

**UEC Surpervisory staff** :

Assoc. Prof. Kohji Higuchi (higuchi@ee.uec.ac.jp)
Tec. Exp. Tatsuyoshi Kajikawa(kajikawa@ee.uec.ac.jp)
TA Yoshihiro Ohta (ohta@francis.ee.uec.ac.jp)

KMUTT Leader :
Lecturer Kamon Jirasereeamornkul (Electronic Engg.. KMUTT)

Number of Training student:
One Trainee student Theeraphat Poomalee from Dept. of Electronic .Engg was accepted to stay at UEC for High Performance Digital Control Experiments of DC-DC Converter training.

# Program agenda

Advanced digital control of a DC-DC converter is performed, and it is verified by experiments that the start-up characteristics and the load sudden change characteristics are improvable. Therefore, the following procedures are required and the training is advanced according to following schedule.

10.18-10.25 Design and Manufacture of DC-DC Converter
10.26-10.31 Design and Manufacture of Digital Controller using DSP
11.1-11.7 Experiments of Start-up Responses
11.8-11.12 Experiments of Dynamic Load Responses
11.13 Presentation of Training Results

# Training results

In this training program, student from KMUTT could manufactured DC-DC Converter
and the con t roller of DC-DC converter using DSP. He could experienced the experiments of high performance digital control of DC-DC converter. He studied the advanced digital control is very good compared to usual PI control from experiments.
Last day he showed the good results which he got by the presentation. This presentation was shown also in KMUTT through the teleconference.

To the following the data of a presentation and photographs of the situation of the presentation and training. are shown.

# Presentation document

# Robust DC-DC buck converter with fully digital controller

At The University of Electro-Communications (UEC), Japan

Presented by Theeraphat Poomalee

King Mongkut's University of Technology Thonburi

# Outline

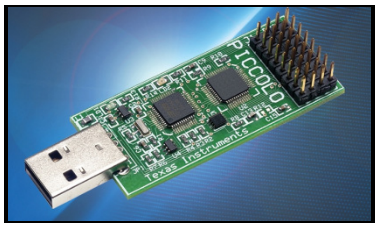
1. Introduction
2. Working principle
3. Closed-loop control
4. Experiment
5. Experimental results
6. Conclusions

# Introduction

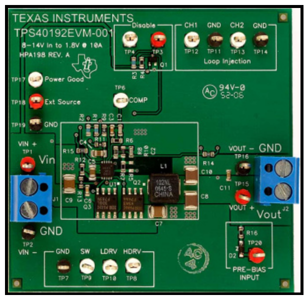
- The demands on switching converter trend to increase its robustness capabilities.

- Conventional analog controller can be replaced by the digital controller to perform high flexible robust control system.

- Using DSP supports more complexity of control algorithm.

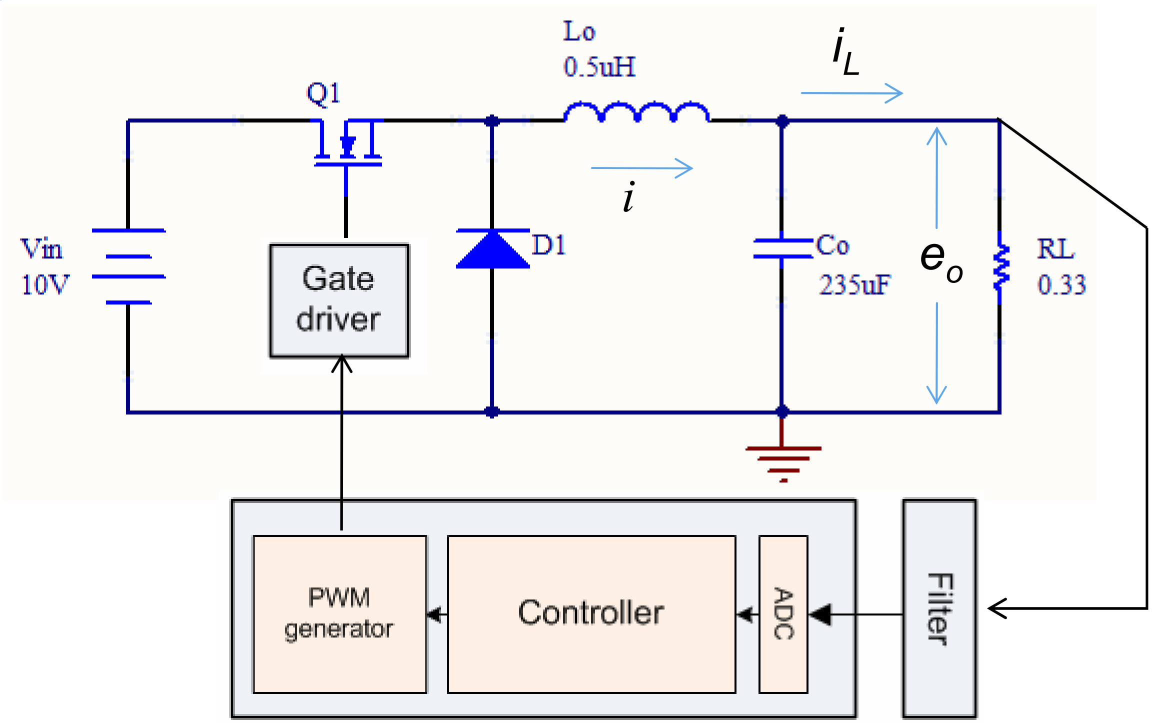


Digital signal processing unit




DC-DC Converter

# Working principle of DC-DC converter




State space model

$$\dot{x} = A_C x + B_C u \qquad y = Cx$$

$$x = \begin{bmatrix} e_o \\ i \end{bmatrix} \quad y = e_O \quad u = e_i \quad G_P = 2$$

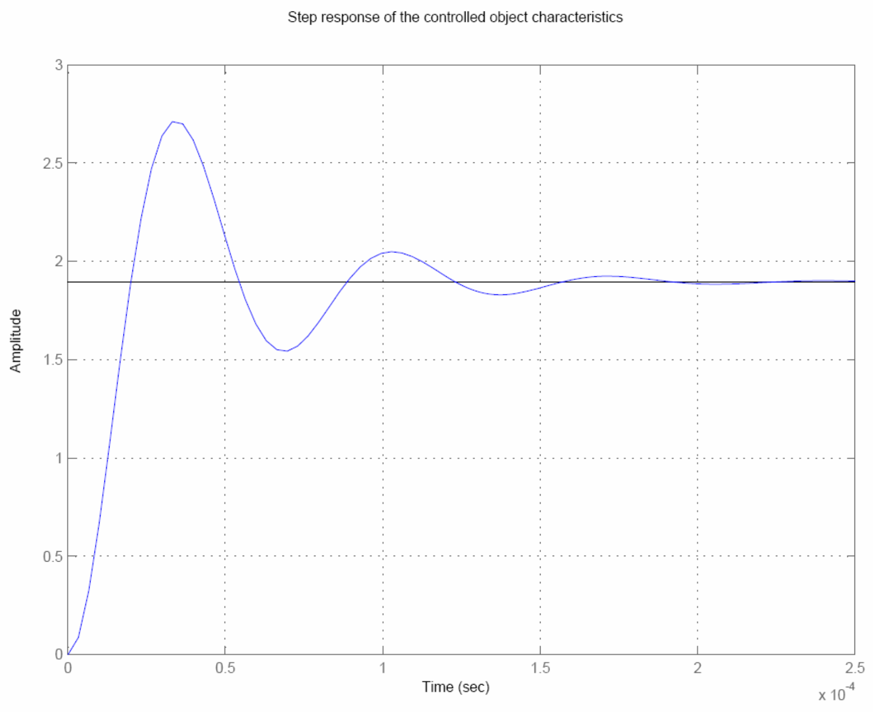
$$A_C = \begin{bmatrix} -\frac{1}{C_O R_L} & \frac{1}{C_O} \\ -\frac{1}{L_O} & -\frac{R_O}{L_O} \end{bmatrix} \qquad B_C = \begin{bmatrix} 0 \\ \frac{G_P}{L_O} \end{bmatrix}$$

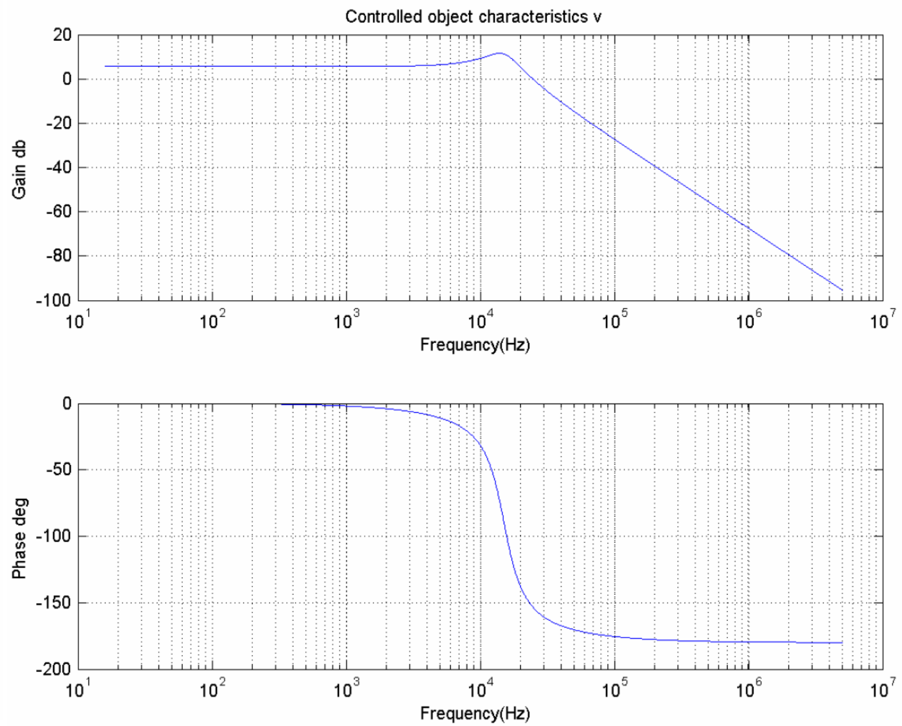
$$C = \begin{bmatrix} 1 & 0 \end{bmatrix}$$

*Ro is combined resistance of the switch Q1 and the inductor Lo.*

# Working principle

Simulation results of the controlled object




Open-loop characteristic of controlled object

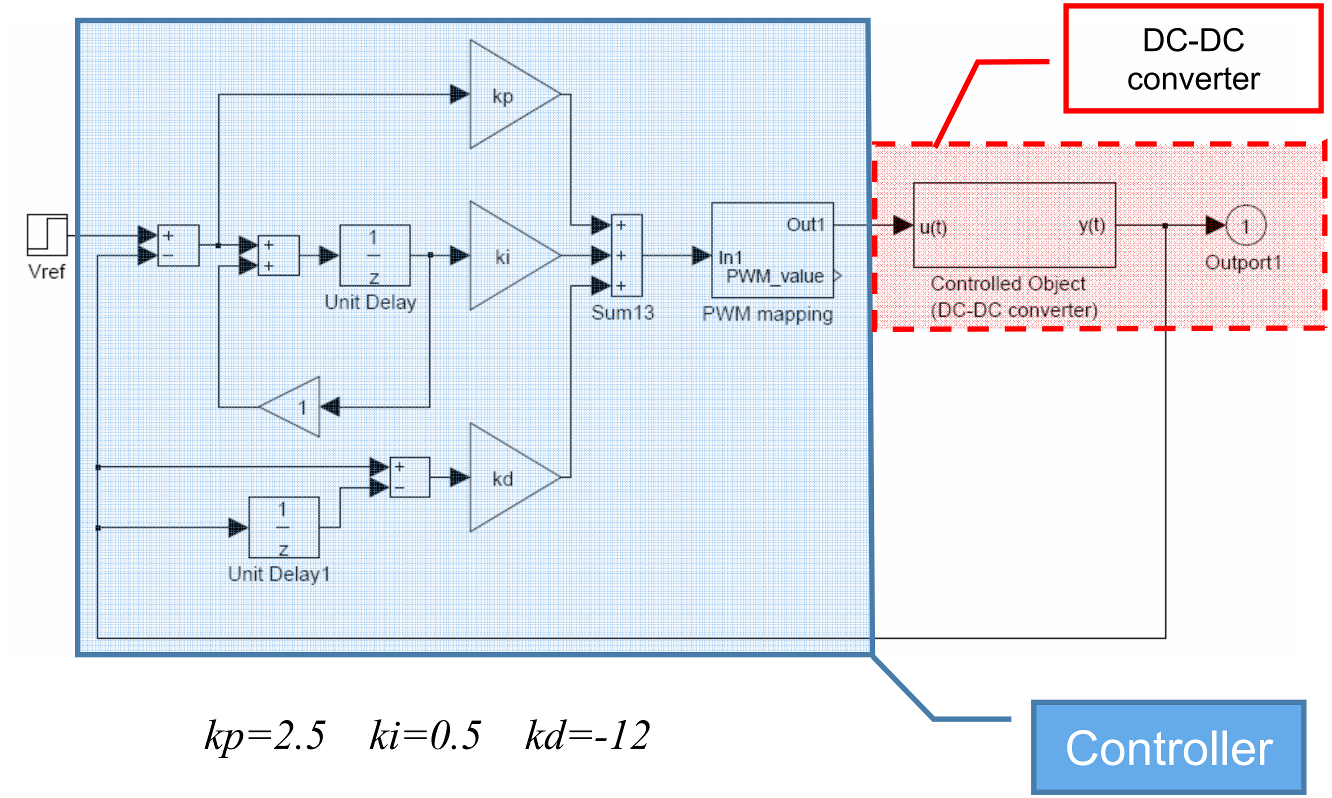
- *RL= 0.33 Ohms*
- *Lo = 0.5 uH*
- *Co = 235 uH*

*System poles* → $-2.44 \times 10^4 \pm 9.15 \times 10^4 i$

*Overshoot = 44%*

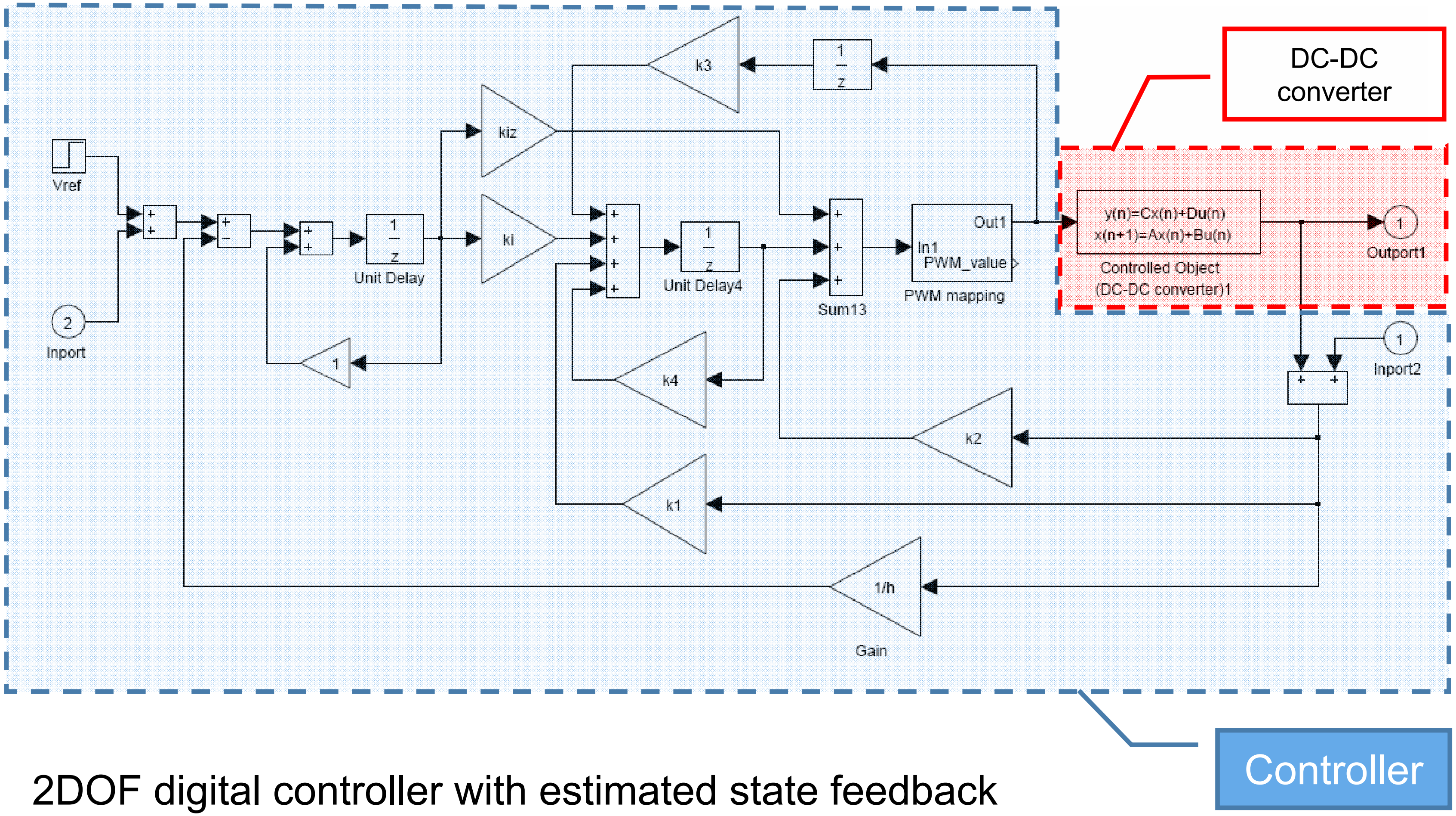
# Closed-loop PID control

Applying simple PID controller




*kp=2.5    ki=0.5    kd=-12*

# Closed-loop robust control




2DOF digital controller with estimated state feedback

# Closed-loop robust control

Applying 2 degree-of-freedom digital controller using state feedback

*k1= (-F(1,1)-F(1,2)*FF(1,1)+((-F(1,4)-F(1,2)*FF(1,4))*(-F(1,2)/FF(1,2)))-(G*H*H4+G*H*Fz)*(Kz)*((1)/(1+H2)))*
*k2= (-F(1,2)/FF(1,2)-G*H*(Kz)*((1)/(1+H2)))*
*k3= (-F(1,3)-F(1,2)*(FF(1,3)))*
*k4= (Fz)*
*ki= (h*(G*H*H4+G*H*Fz)*(Kz)*(1))*
*kiz= (h*G*H*Kz)*

$$Ad = \begin{bmatrix} e^{A_c T} & e^{A_c (T - L_d)} & \int_0^{Ld} e^{A_c \tau} B_c \, d\tau \\ 0 & 0 & 0 \end{bmatrix}$$

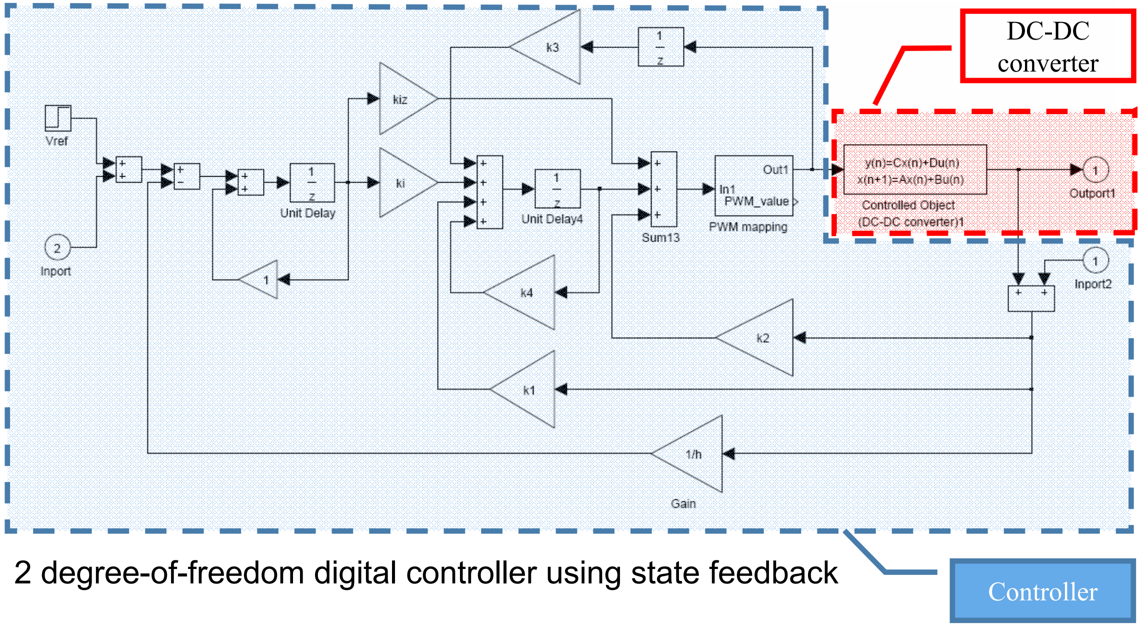
$$B_d = \begin{bmatrix} \int_0^{T-Ld} e^{A_c \tau} B_c \, d\tau \\ 1 \end{bmatrix}$$

$$C_d = \begin{bmatrix} C & 0 \end{bmatrix}$$

where
*FF(1,4)=-Bd(1,1)/Ad(1,2)*
*FF(1,2)=Ad(1,2)*
*FF(1,1)=-Ad(1,1)/Ad(1,2)*
*FF(1,3)=-Ad(1,3)/Ad(1,2)*
*Fz=-F(1,4)-F(1,2)*FF(1,4)*

And
*Ad, Bd are expanded discrete time state space model.*
*F is state feed-back matrices.*
*GH is steady state gain.*

# Experiment




2 degree-of-freedom digital controller using state feedback

- ❖ Input voltage = 9-11 V
- ❖ Output voltage = 3.3 V
- ❖ Output ripple at full load < 100 $mV_{rms}$

Controller properties

- ❖ PWM frequency 200 kHz
- ❖ PWM step resolution 150

*H1=-0.2*
*H2=-0.9*
*H3=-0.1*
*H4=-0.5*
*Kz=0.2*

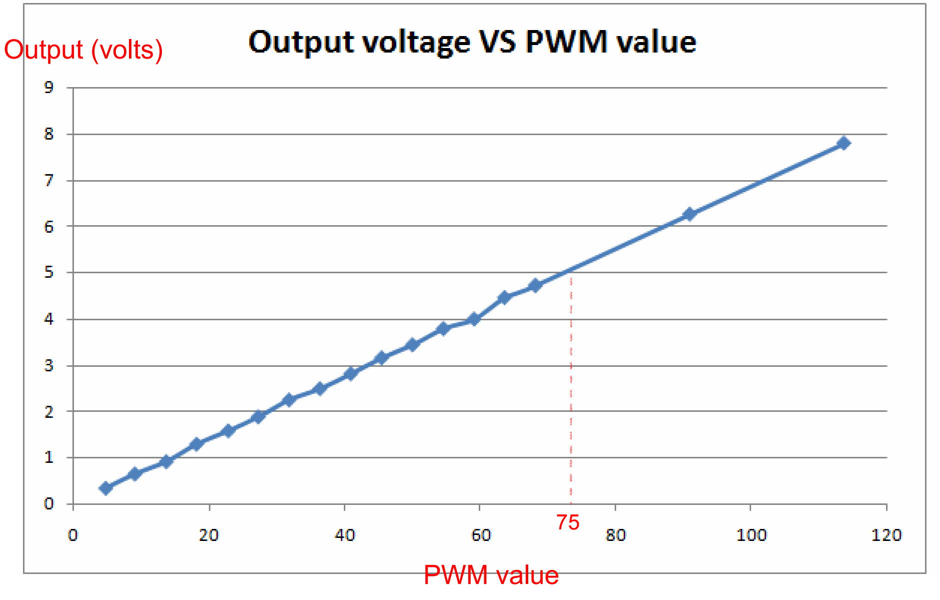
Desired feedback system poles & zeroes

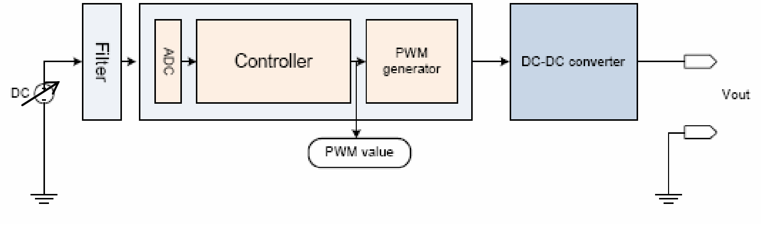
*k1=0.3402*
*k2=0.0210*
*k3=-0.0058*
*k4=0.1122*
*ki=-0.0301*
*kiz=0.0727*

Parameters of controller

# Experiment

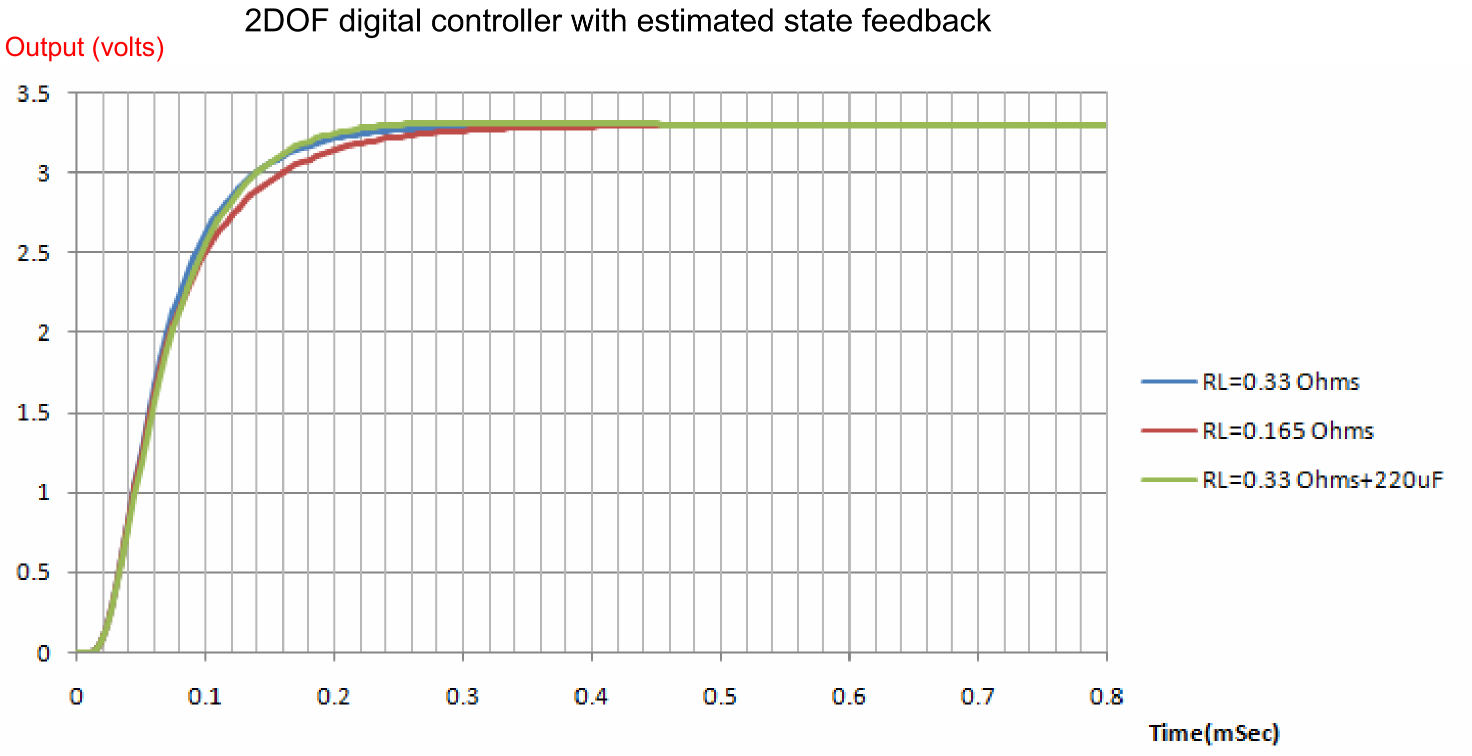
Open loop gain of the plant testing




- *Switching frequency = 200 kHz*
- *Sampling frequency = 200 kHz*
- *PWM value 0-150 is mapped into duty cycle 0-100*
- *Input voltage of converter = 10 Volts*

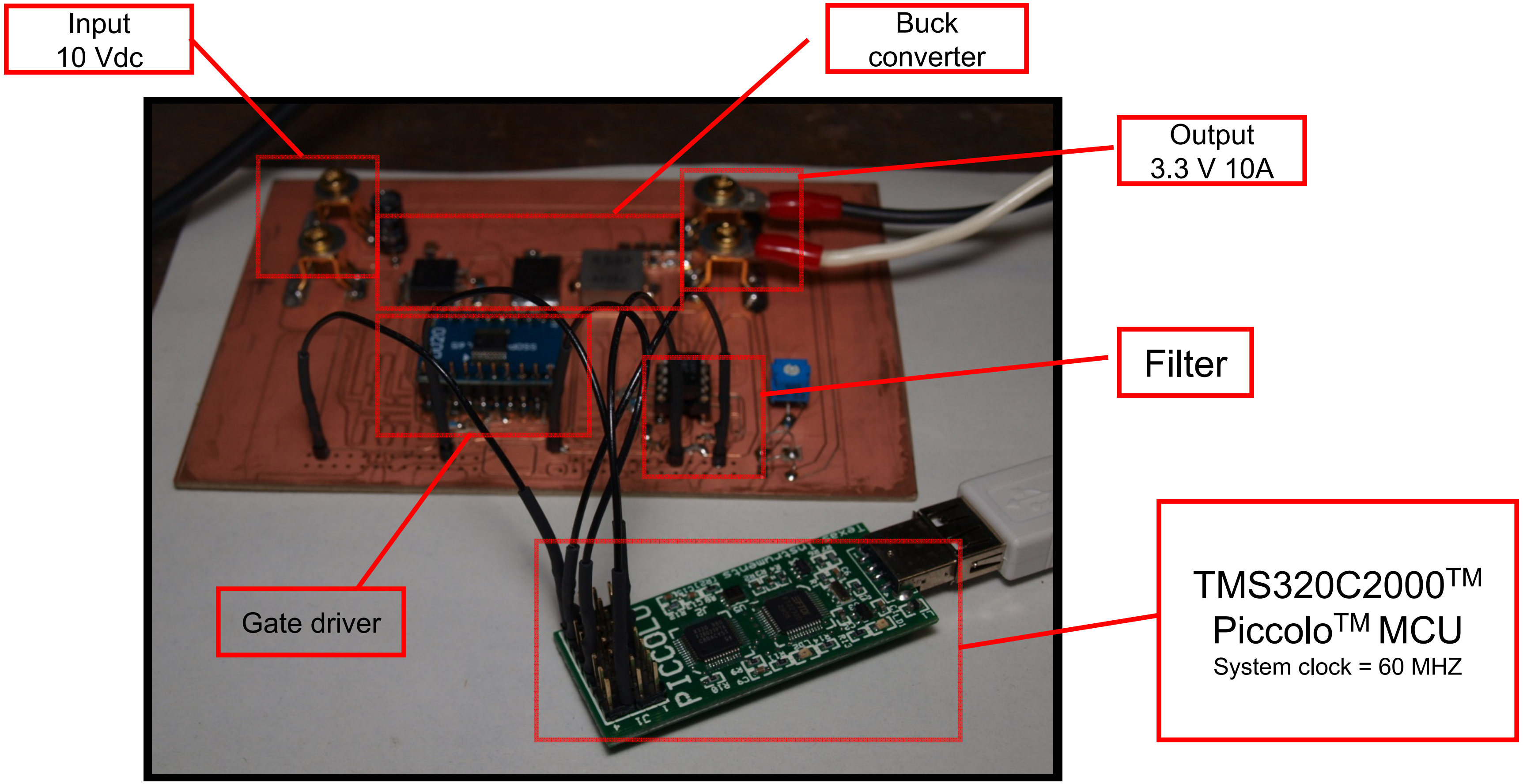
# Simulation results




Step response in different load

# Experimental results

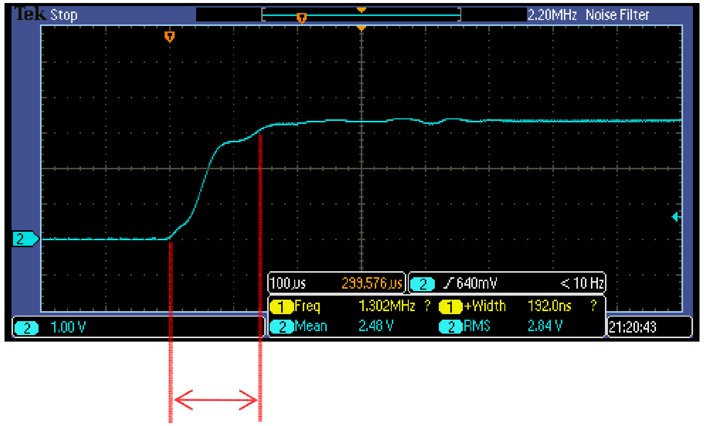
Hardware implementation



# Experimental results

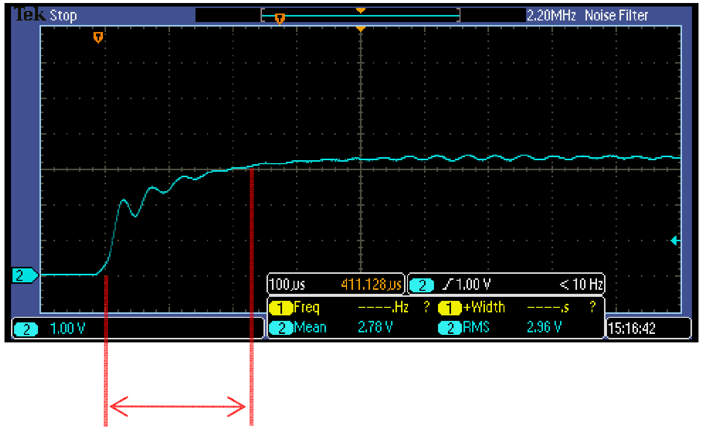
Start-up response

2 DOF digital controller




Start-up time = 140 uS

PID controller



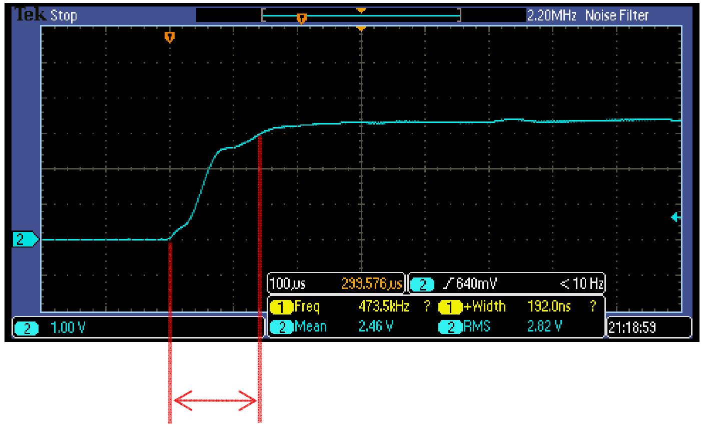

Start-up time = 225 uS

$R_L = 0.33 Ohms$ Time/DIV = 100uS

# Experimental results

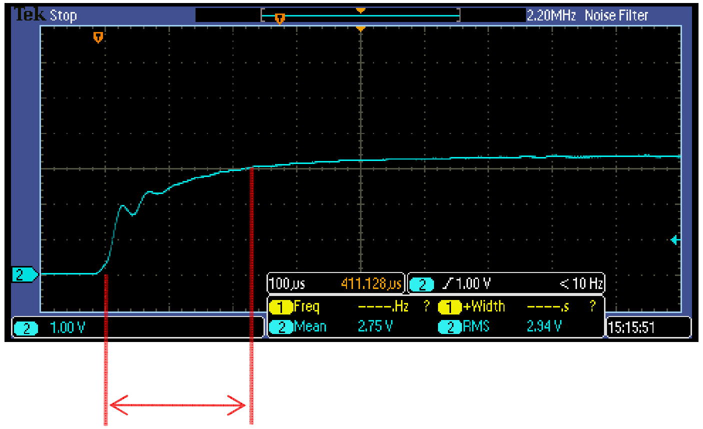
Start-up response

2 DOF digital controller




Start-up time = 140 uS

PID controller



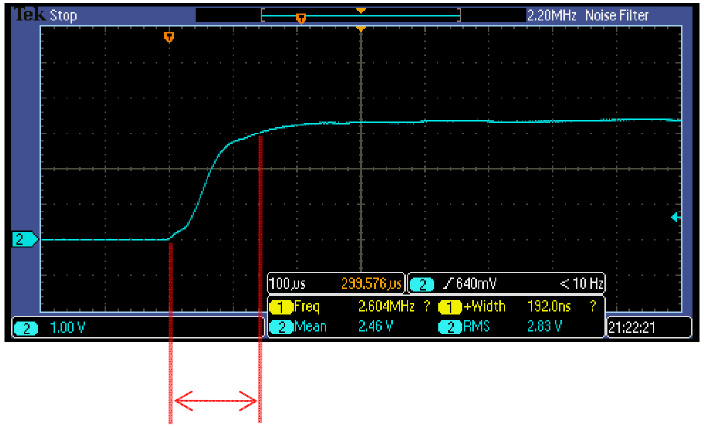

Start-up time = 225 uS

$R_L = 0.25\ Ohms$ Time/DIV = 100uS

# Experimental results

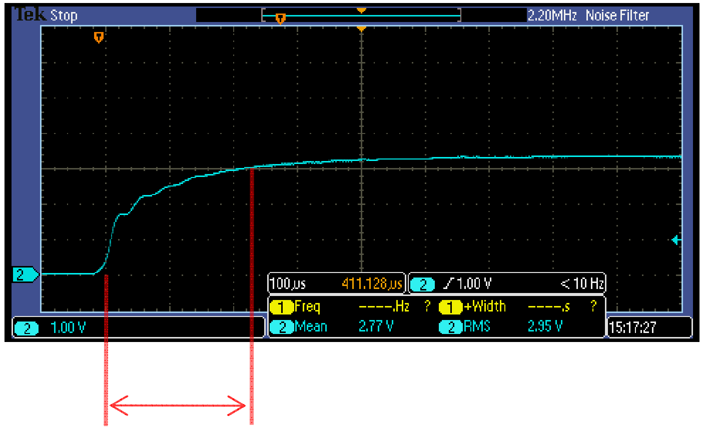
Start-up response

2 DOF digital controller




Start-up time = 140 uS

PID controller

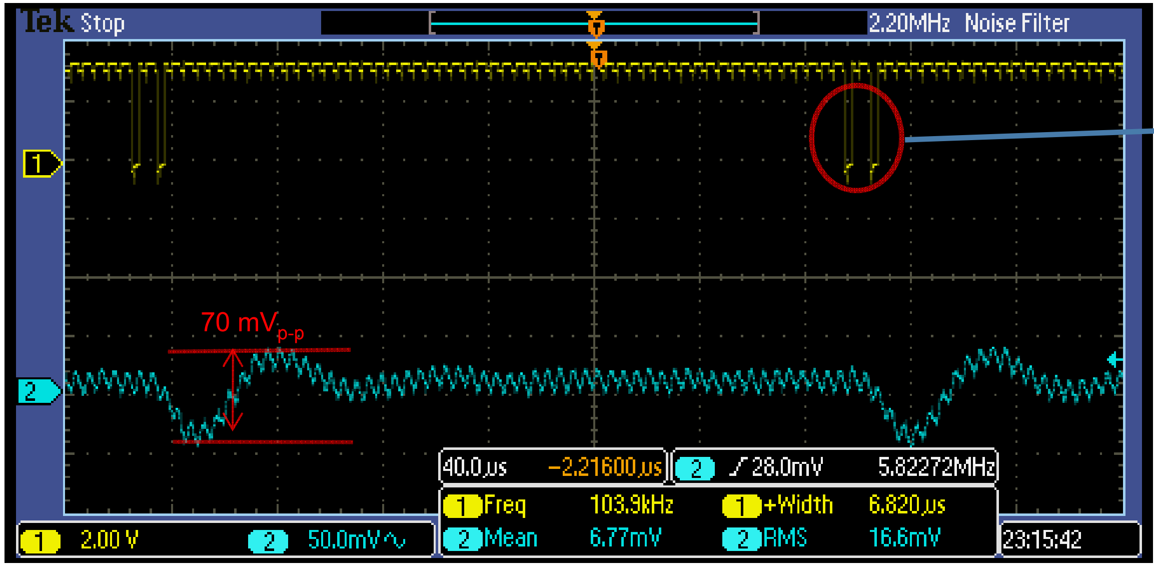



Start-up time = 225 uS

$R_L = 0.33+220uF\ Ohms$ Time/DIV = 100uS

# Experimental results

Steady state




Event indicator shows the alteration of the duty cycle

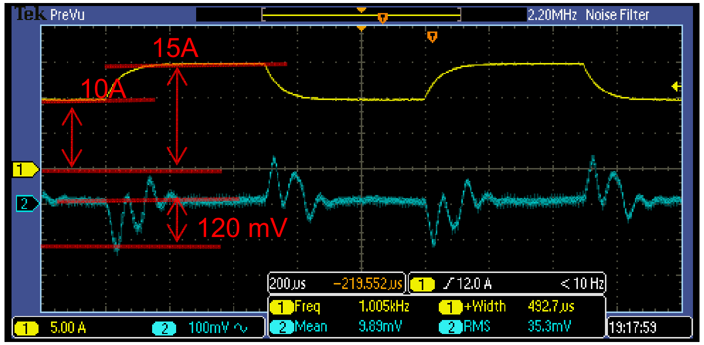
$R_L = 0.33$ *Ohms*

Output ripple = 70 $mV_{p\text{-}p}$
Time/DIV = 100uS

# Experimental results

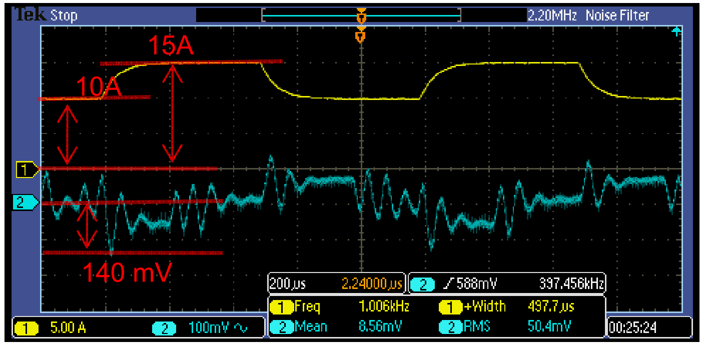
Dynamic load response

2 DOF digital controller




Output voltage variation = 120mV
Time/DIV = 200uS

PID controller




Output voltage variation = 140mV
Time/DIV = 200uS

# Experimental results

## 2 DOF digital controller

❖Provides fast start-up and good dynamic-load response.
❖No overshoot and ringing appeared in start-up phase within various load.

## Simple PID controller

❖Some ringing and overshoot may be arisen in start-up period.
❖Slower response to the dynamic load.
❖Fast controller and higher loop gain may produce some oscillation.

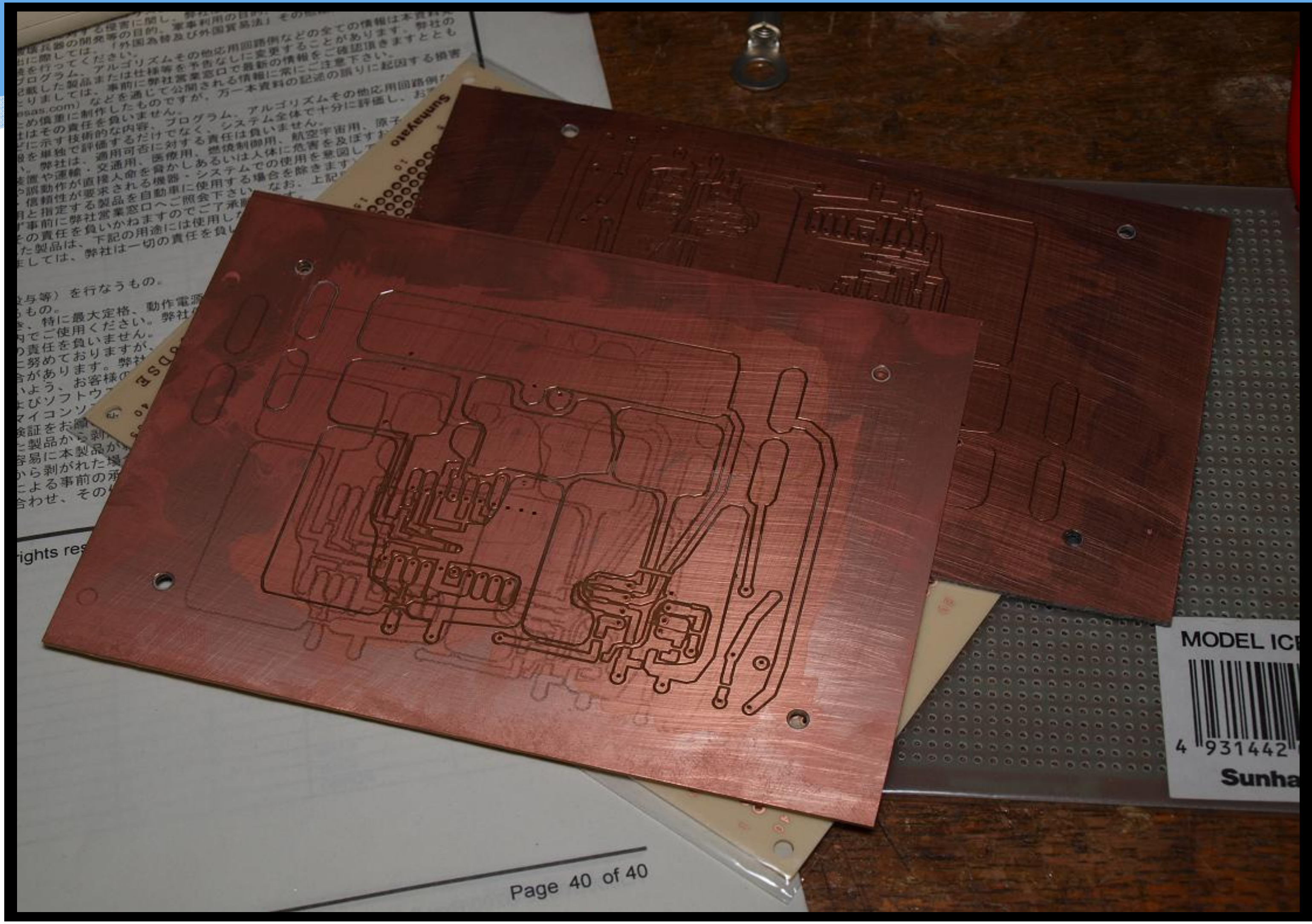
# Conclusions

- The robust control algorithm can be achieved via the use of digital controller .
- The implemented system can overcome the variation of dynamic load as well as good start-up response.
- Only output voltage feedback is used.
- The proposed algorithm requires high performance DSP and high resolution of PWM generator.

# Reference

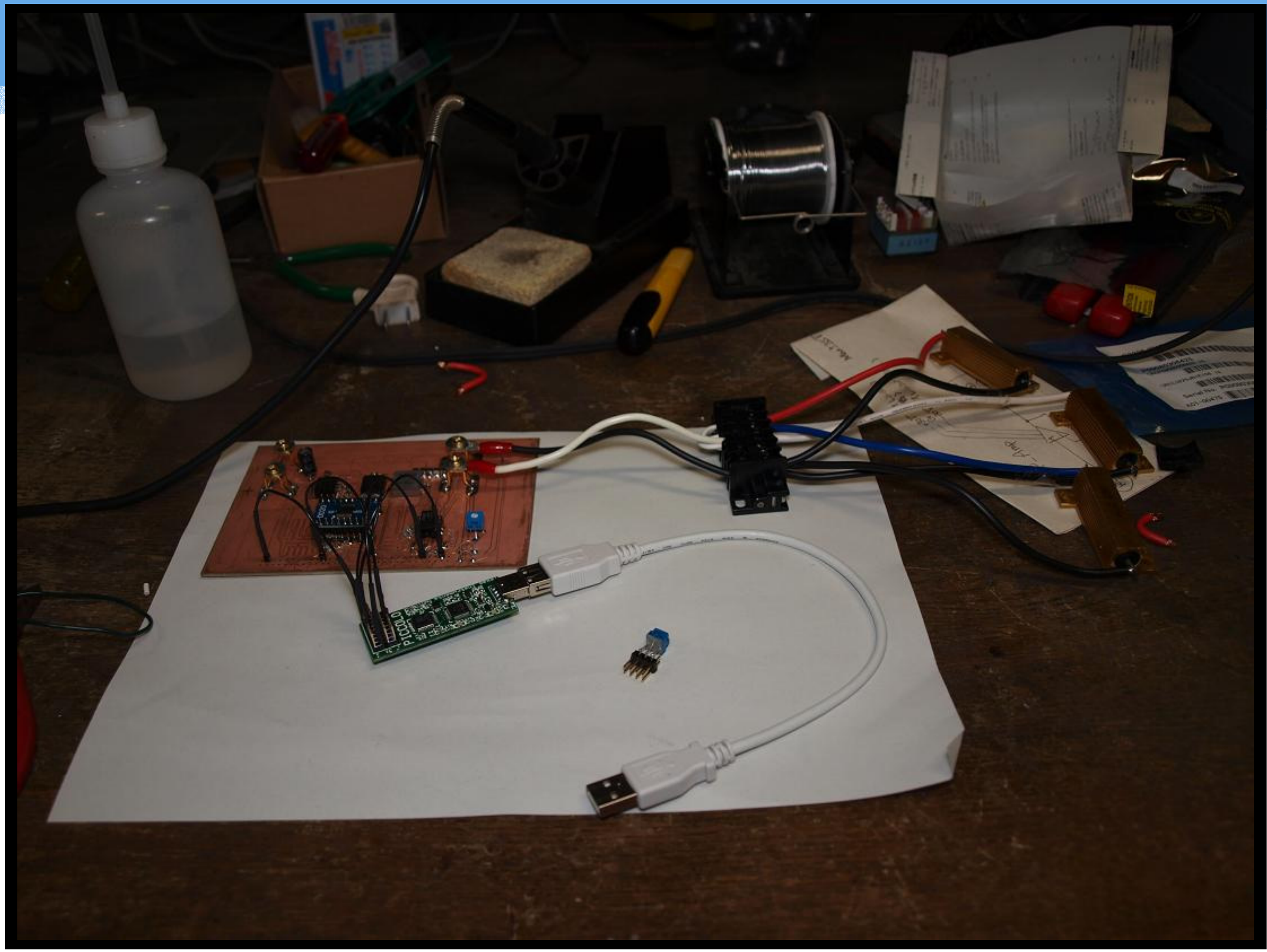
[1] E. Takegami, K. Higuchi, K. Nakano, S. Tomioka, and K.Watanabe "The Method for Determining Parameters of Approximate 2DOF Digital Controller for Robust Control of DC-DC Converter" ECTI transactions on electrical eng., electronics, and communications vol.4, no.1 february, 2006.

# Training



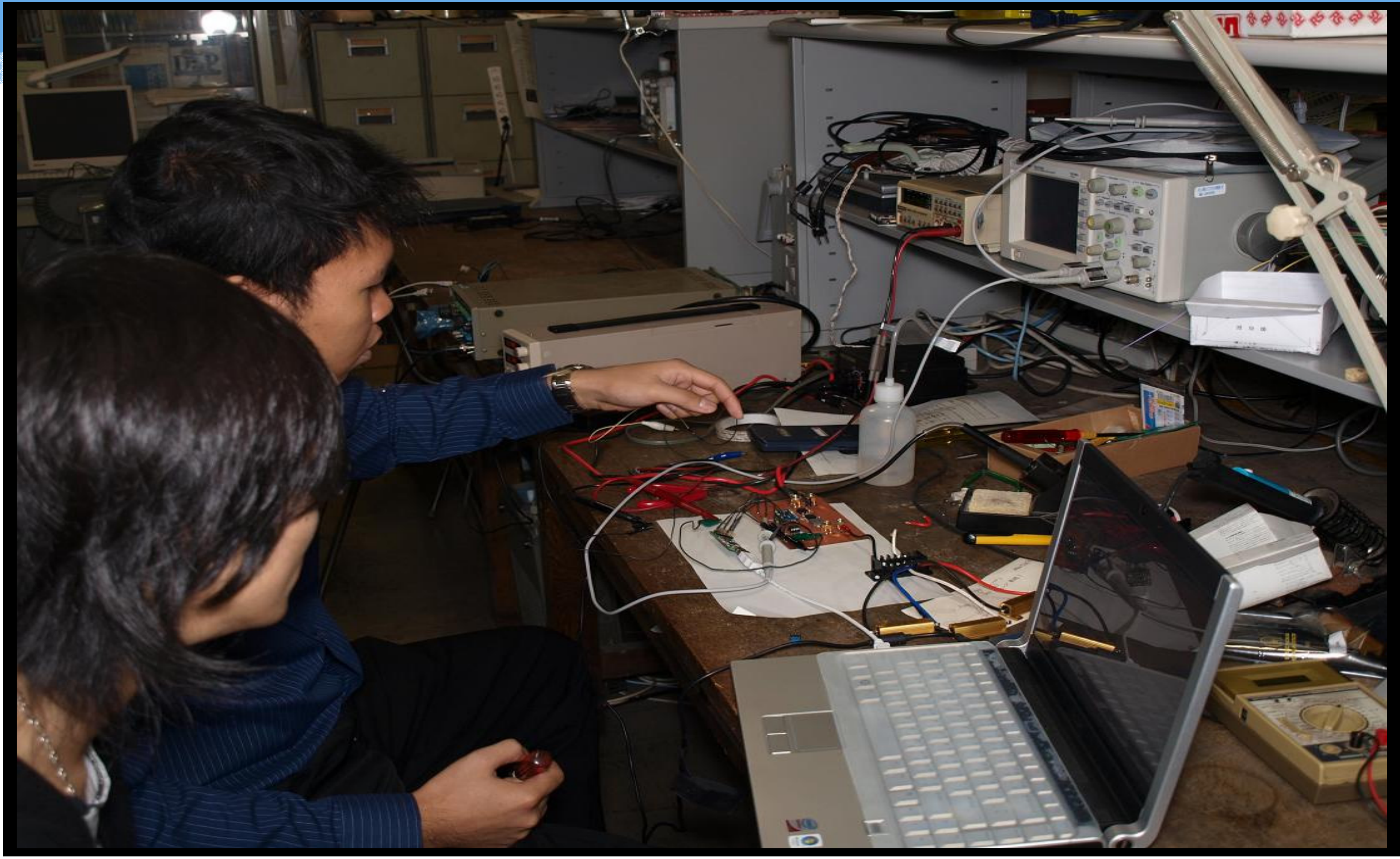

Some prepared PCBs of DC-DC converter

# Training



Assembled hardware of DC-DC converter

# Training

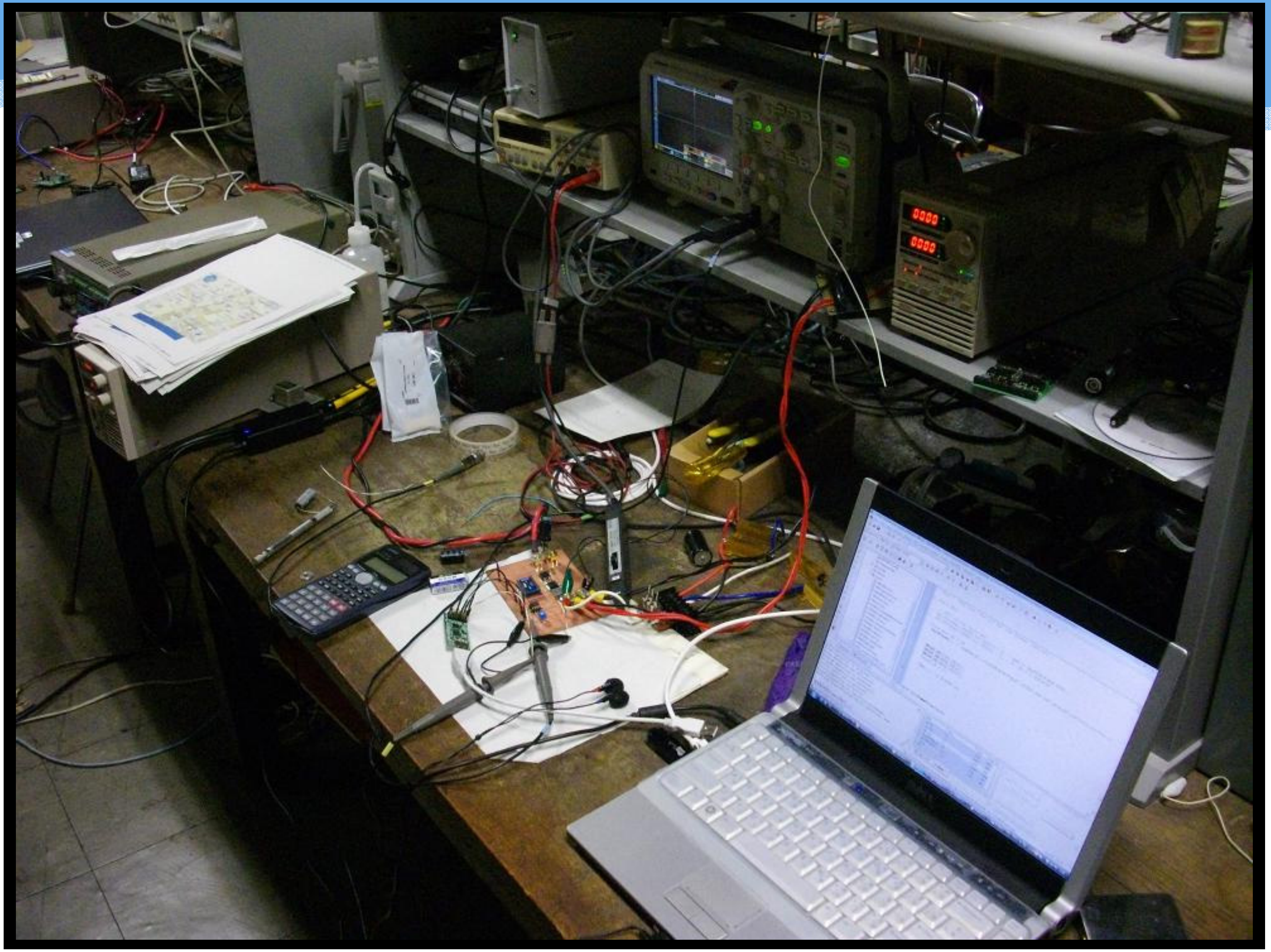


Get training how to program the microcontroller

# Training

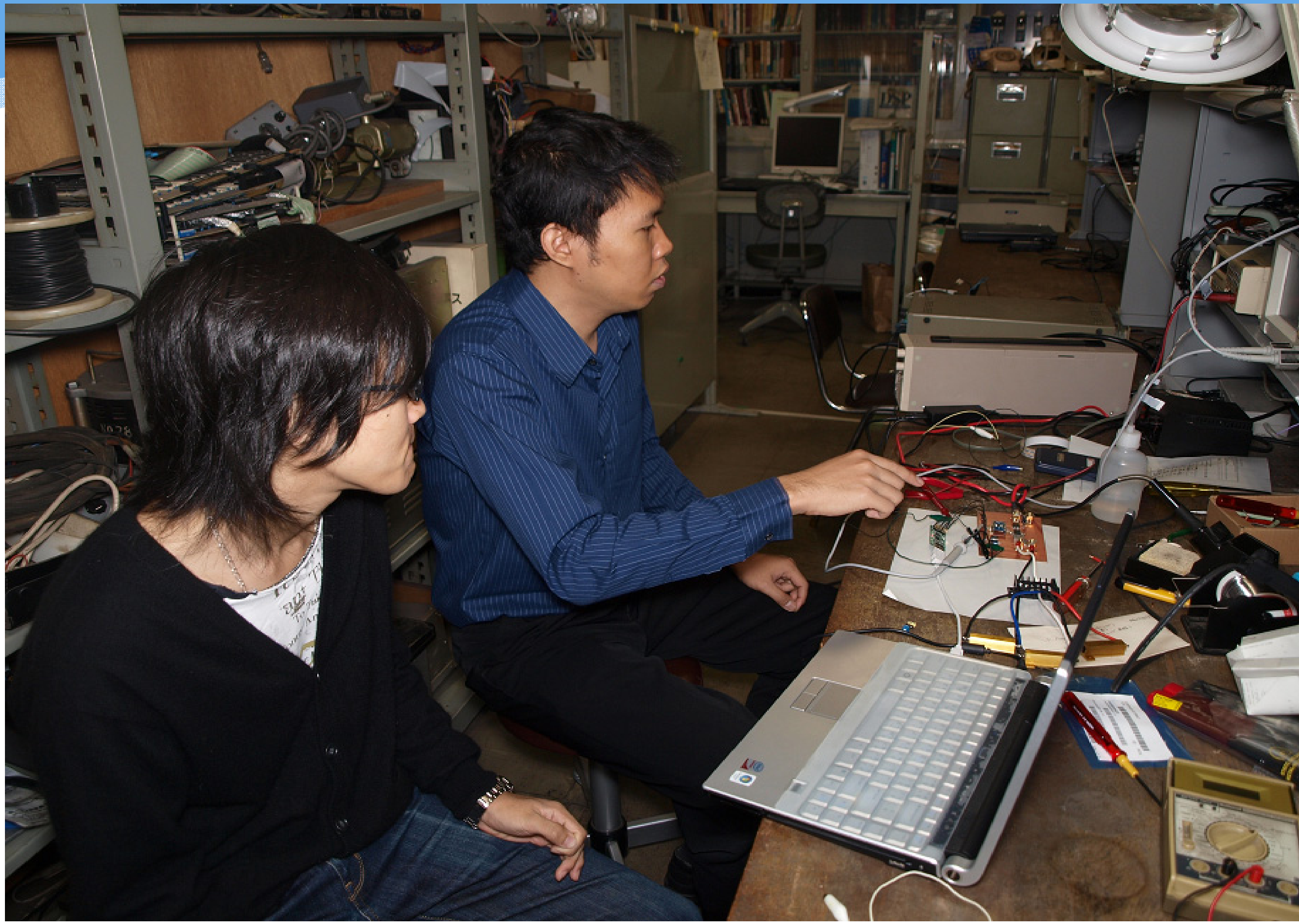

Some control algorithm explanation

# Training



Working site

# Training



Teeraphat and TA Ohta

# Training


Show training to KMUTT, Small screen is KMUTT

# Training

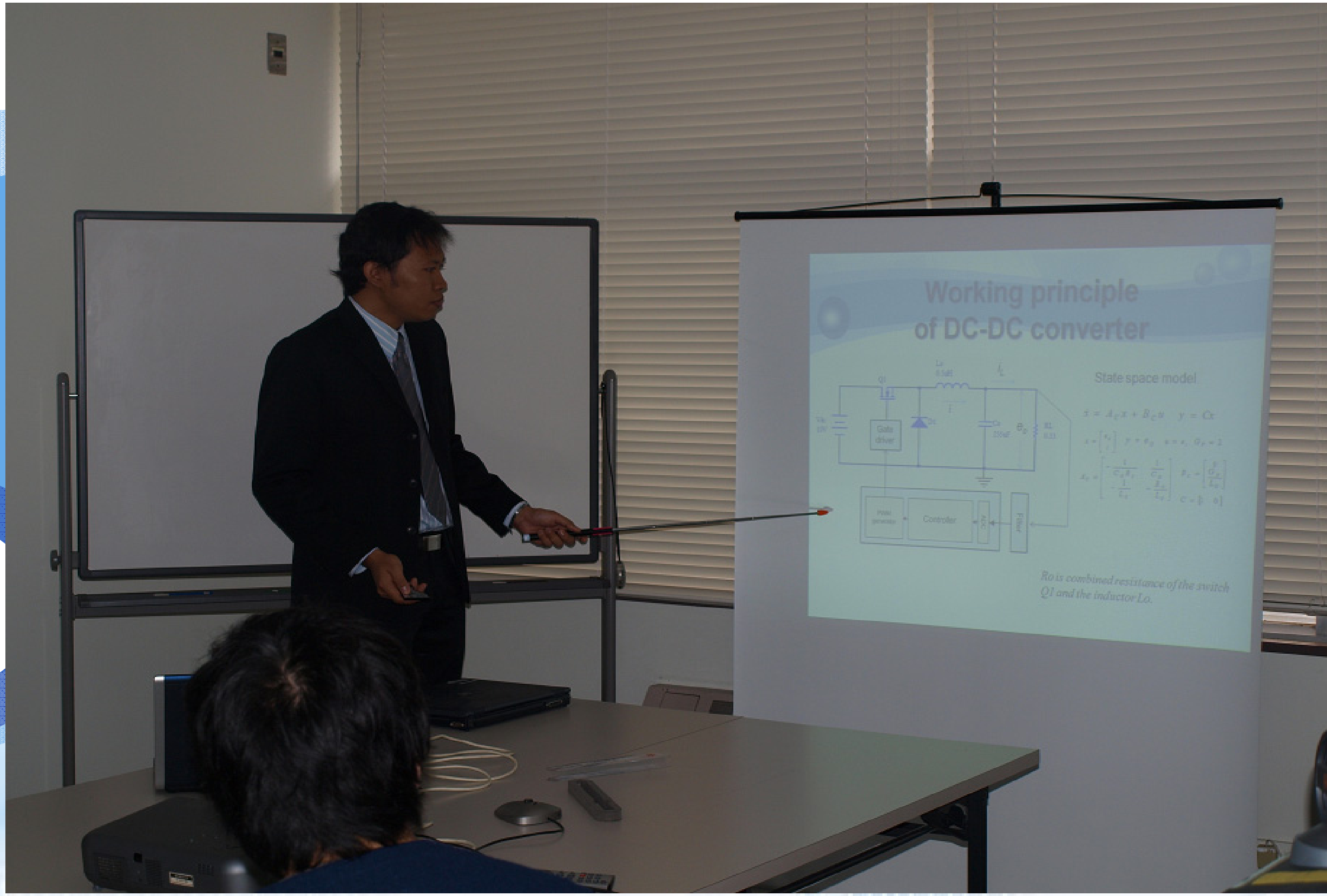
Show training to KMUTT using teleconference

Ohta, Kamon, Higuchi, Teeraphat

# Training

Participated in lab meeting

# Presentation

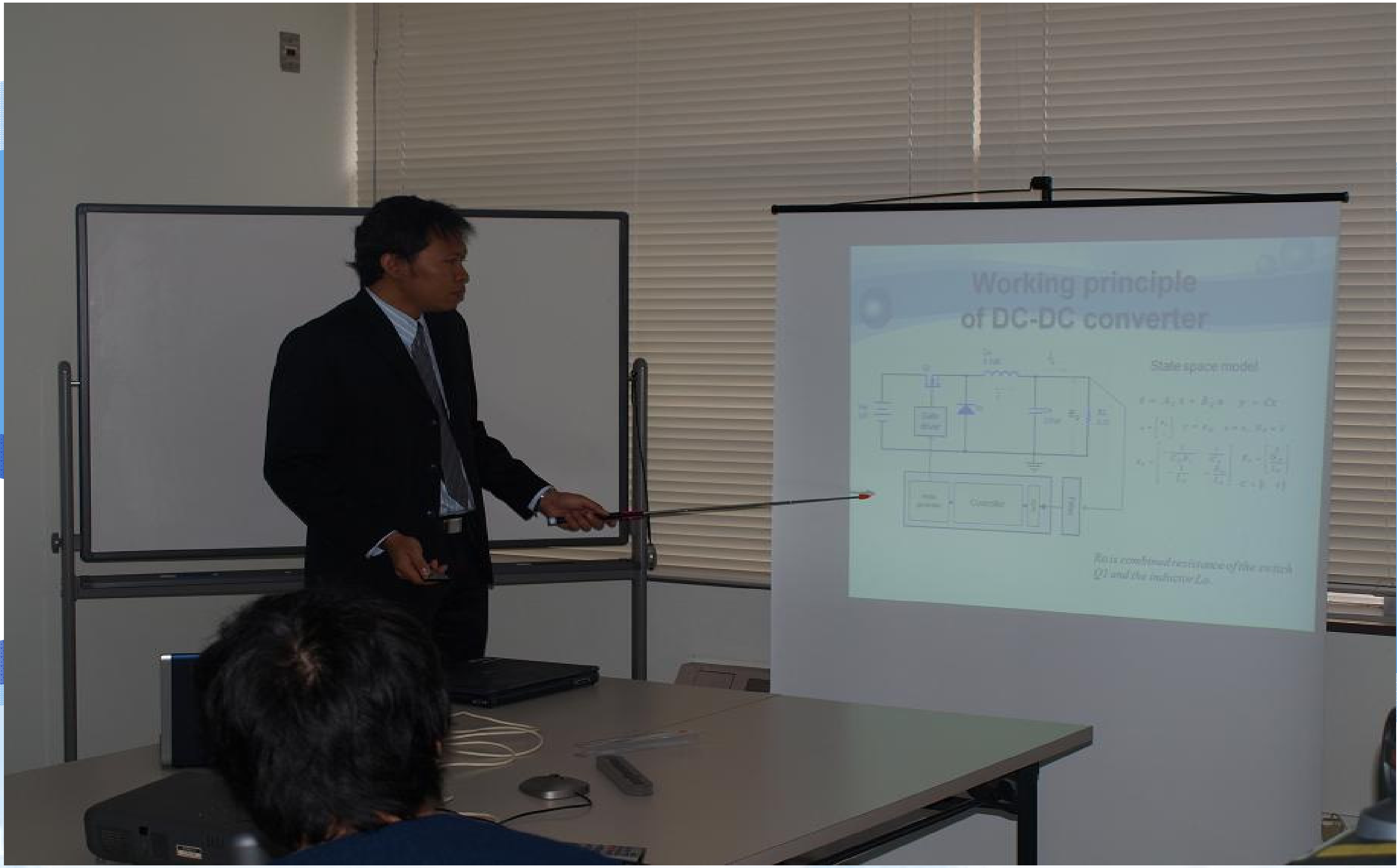



## Theeraphat Poomalee

# Presentation

Higuchi lab members

# Presentation




Theeraphat Poomalee

# Presentation

Discussion together with KMUTT

# Presentation

Show presentation to KMUTT
Vice President of KMUTT and Prof. Kosin

# Presentation

KMUTT students ask questions

# Presentation


Prof. Miki ask questions