

HIGH-PERFORMANCE
SIGNAL & POWER INTEGRITY

HIGH-PERFORMANCE
IC DESIGN & VERIFICATION

FIRST-PASS
SYSTEM
SUCCESS

APPLICATION WORKSHOPS FOR
HIGH-PERFORMANCE ELECTRONIC DESIGN

Digital PWM Controlled DC-DC Switching Power Supply

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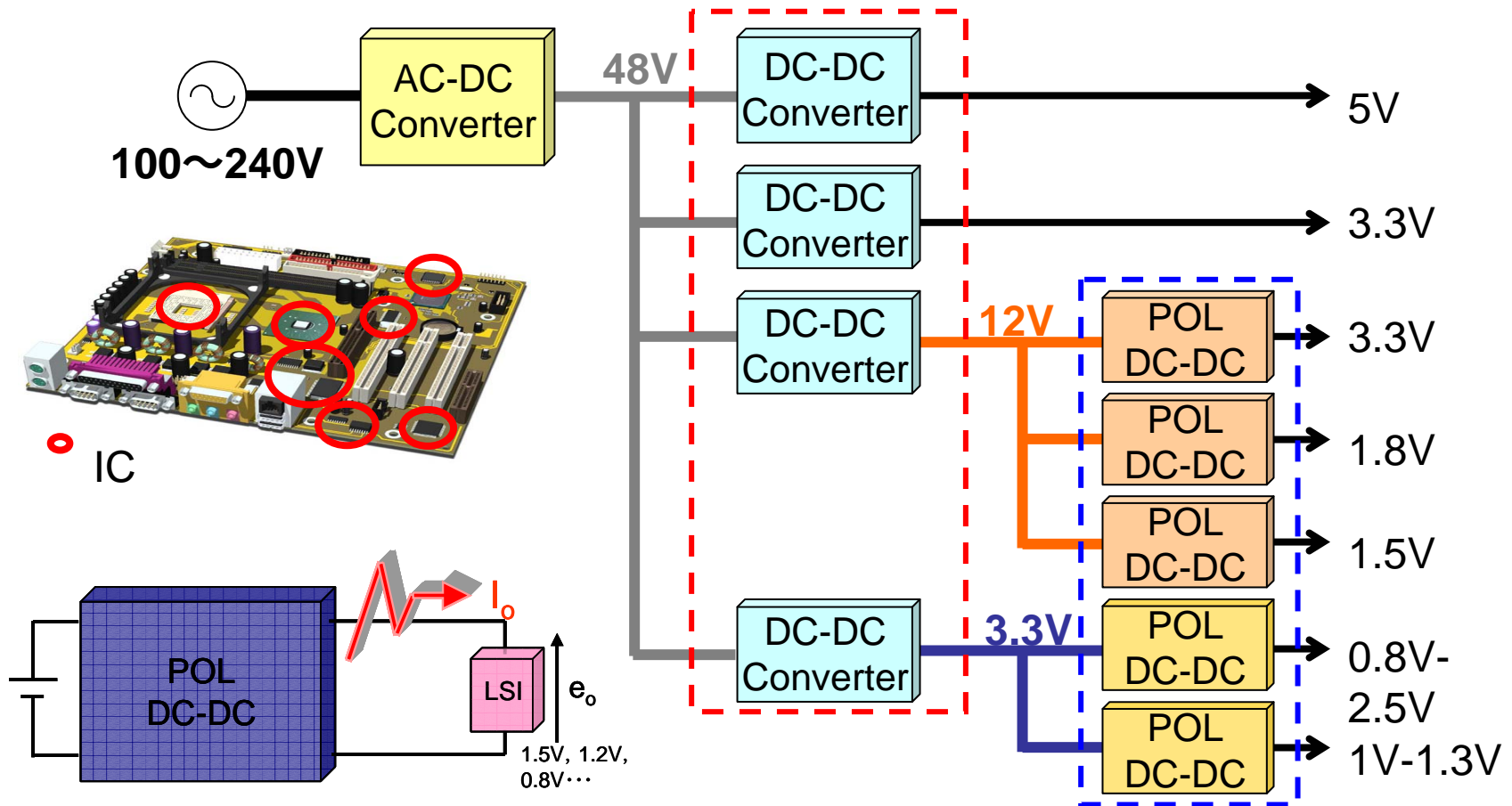
Nagasaki University

HIGH-PERFORMANCE
ELECTROMECHANICAL SYSTEMS

HIGH-PERFORMANCE
RF & MICROWAVE

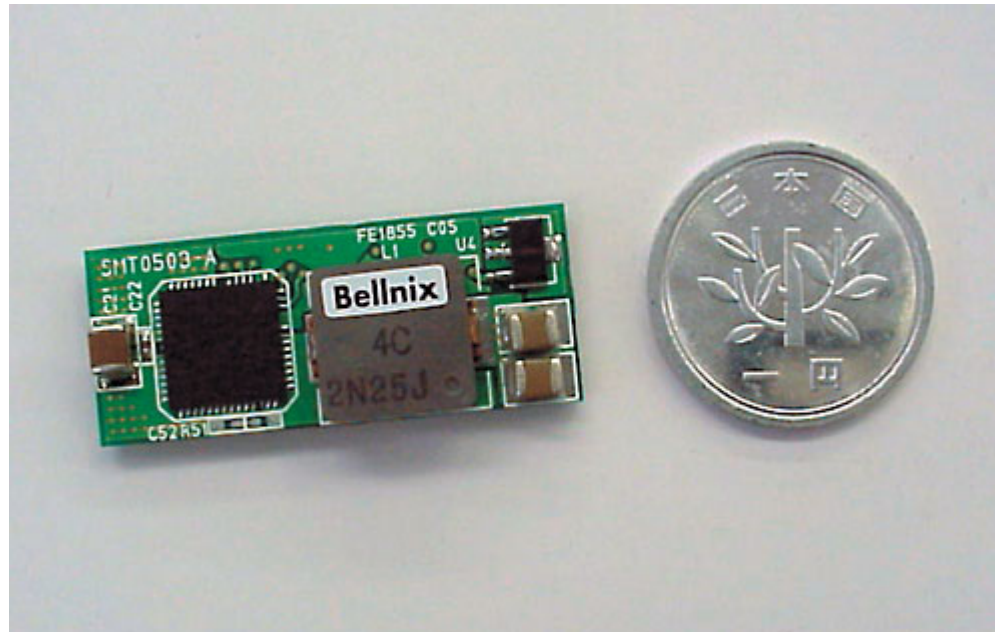


Distributed Power Supply



Power POL Converter

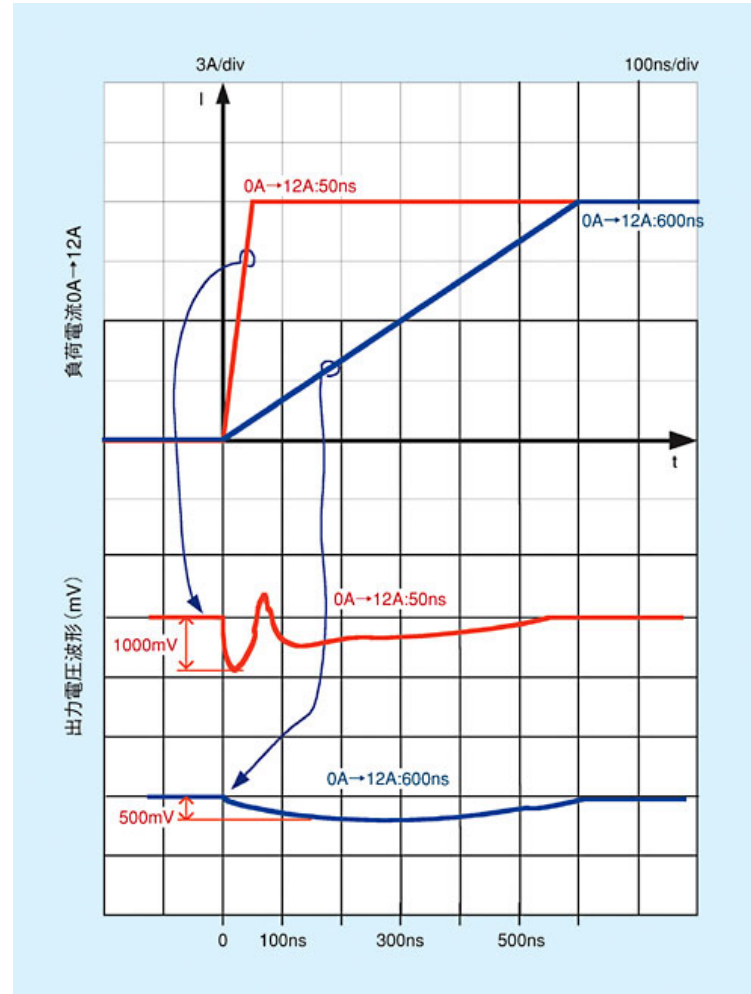
Bellnix[®]



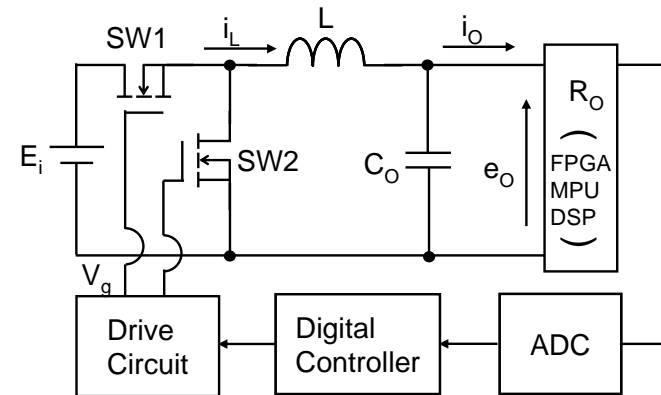
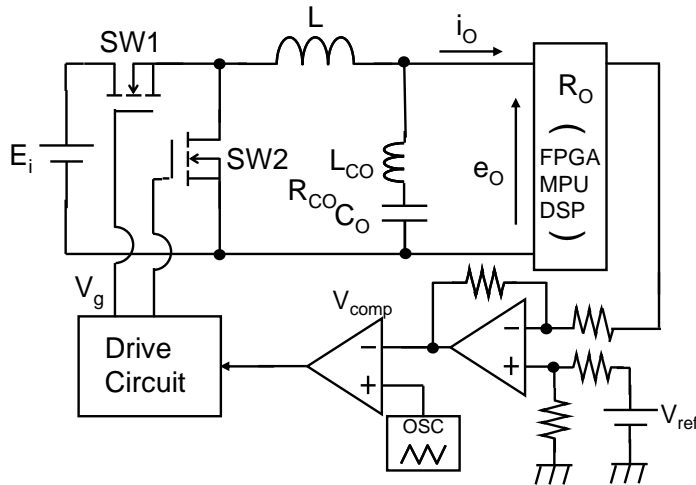
1 V 20 A POL Converter



Through rate and voltage



Analog and Digital Control



Analog PWM

Merit : Low Cost , Simple

Demerit : Weak from noise

Difficult for Advanced Control

Conventional Digital PWM

Merit : Flexible , Advanced Control

Demerit : High Cost, Low Speed

Slow Response Time

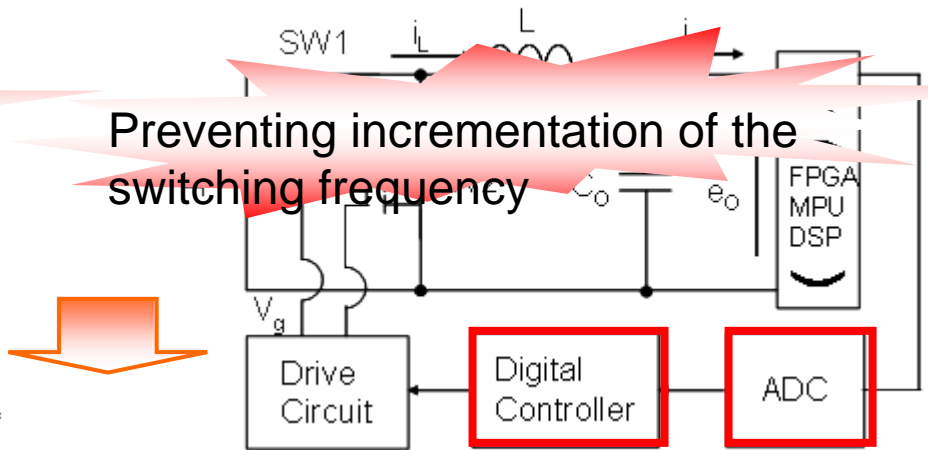
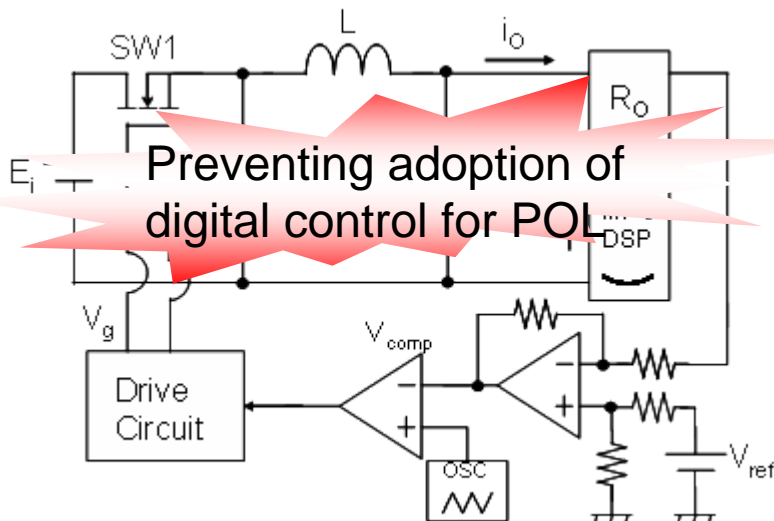
We propose new Digital controlled PWM



Digital Control PWM

Merits (especially large problems for point of load(POL))

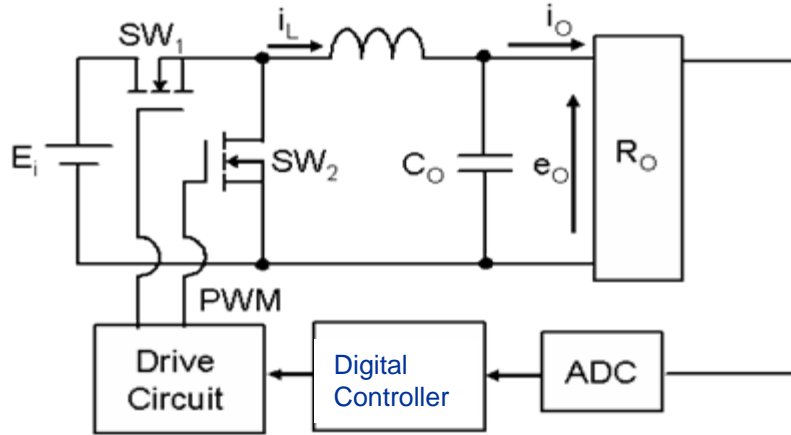
- Robustness (Or flexible control for various operating conditions)
- Programmability



Common Low-cost and high-speed response TRADE-OFF rol POL



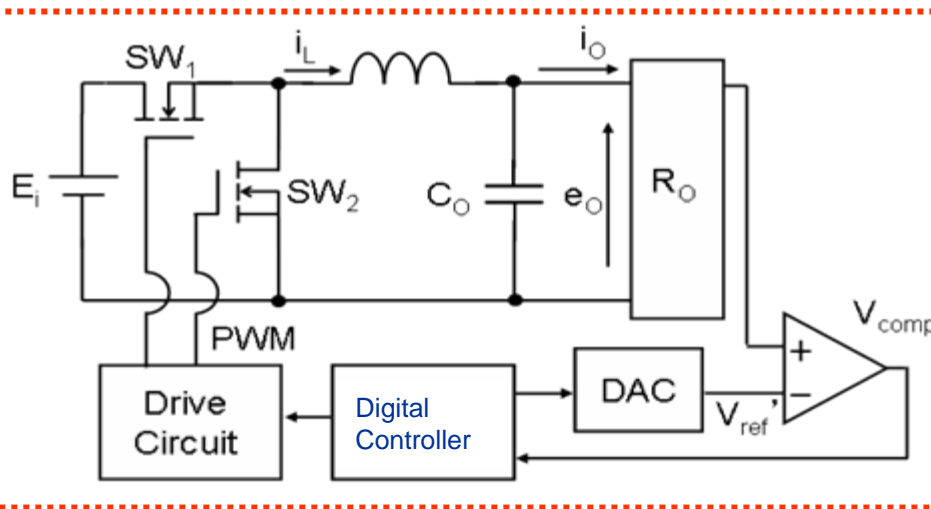
Proposed System



Common digital control
DC-DC converter

Main Improved Points

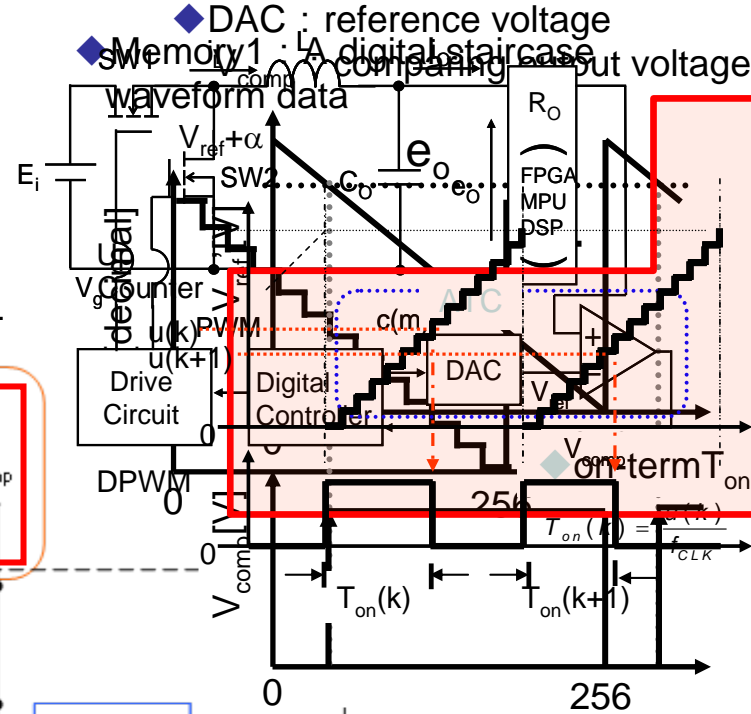
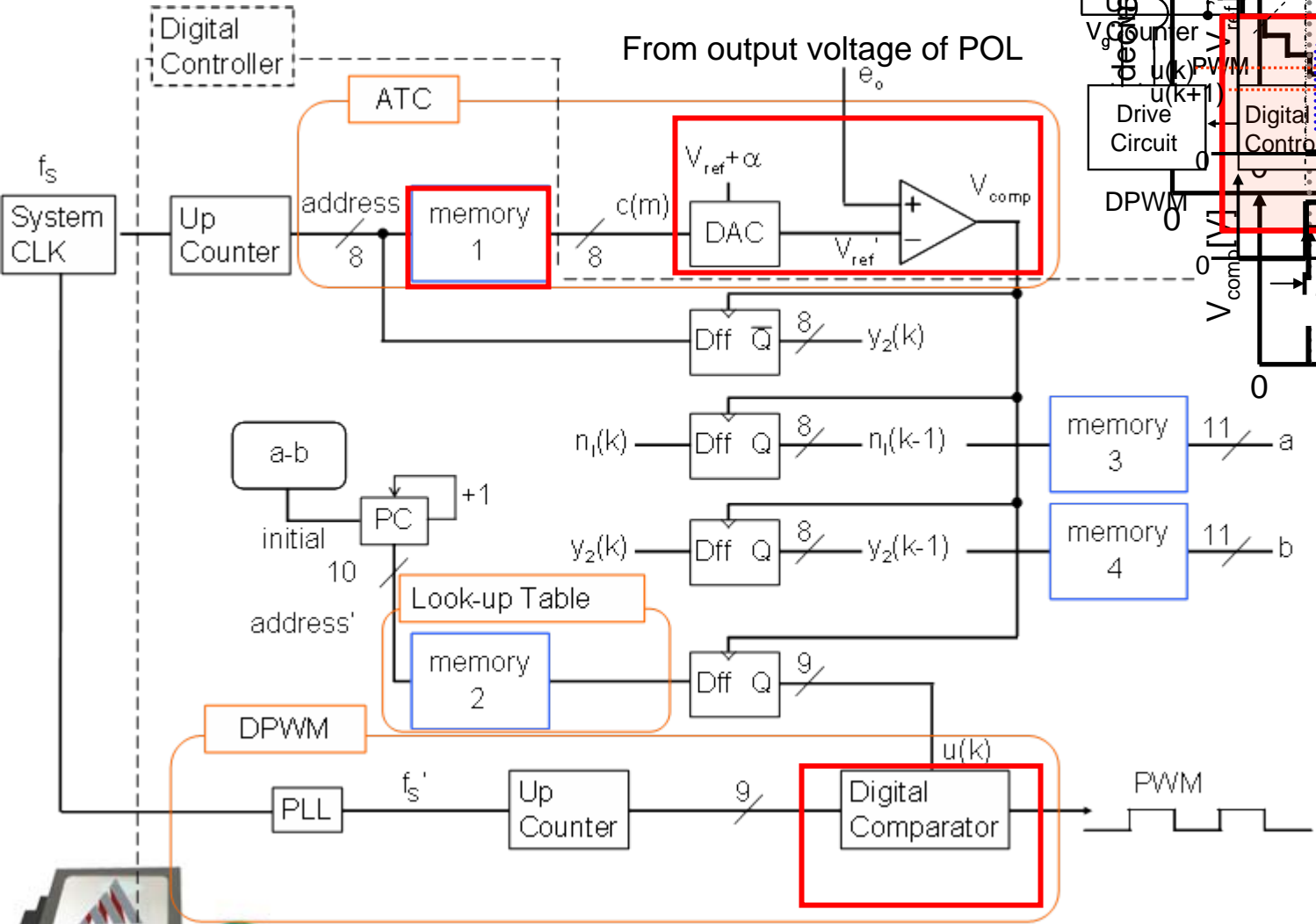
- ADC → DAC & Analog Comparator (Cost Suppression)
- Serial Operation → Parallel Operation (Delay Time Suppression)
- Real Time PID Operation



Proposed Digital PWM Control
DC-DC converter

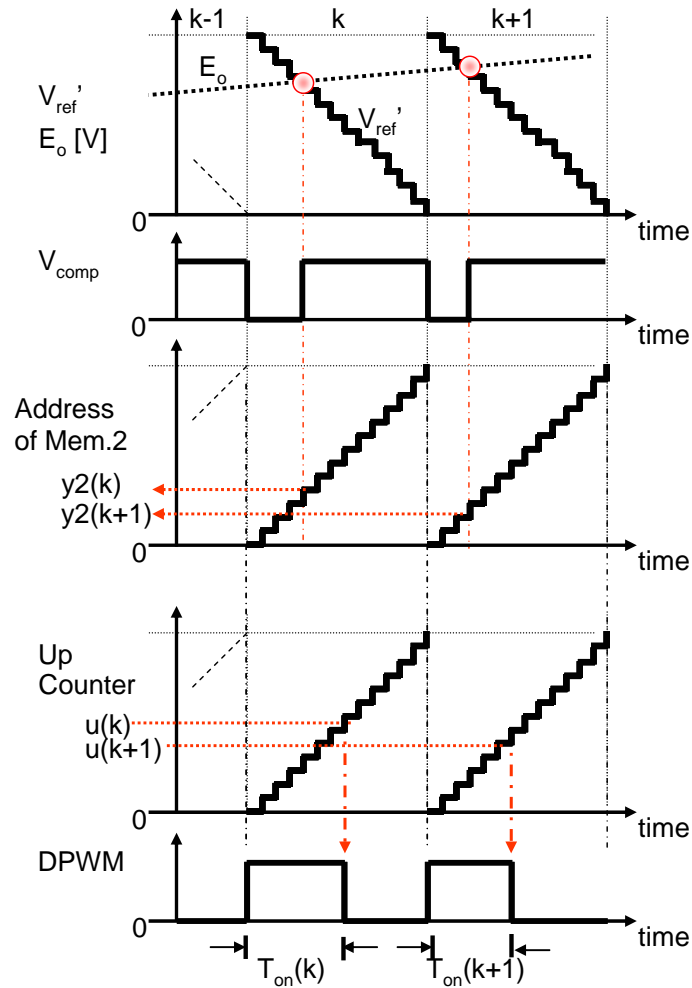


Proposed System

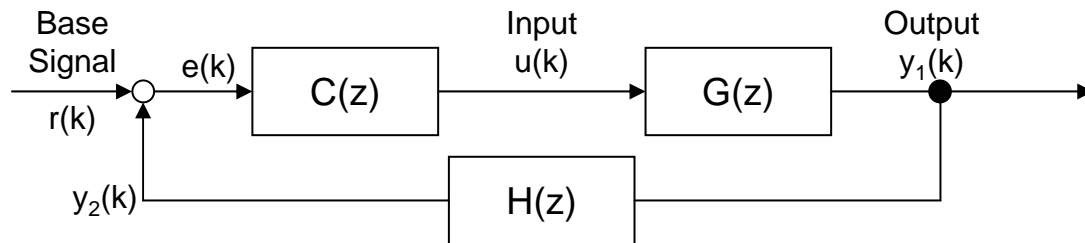


Theoretical Waveforms

call
memory2
(PID LUT)
read



PID control with Look-up Table



General digital PID control law

$$u(k) = u_{Ref} + \underbrace{K_P e(k)}_P + \underbrace{K_I n_I(k)}_I + \underbrace{K_D (e(k) - e(k-1))}_D$$

u_{Ref} : a reference value of $u(k)$

$e(k)$: an digitalized error value (e_o and V_{ref})

$n_I(k) = n_I(k-1) + e(k)$: an integral data of $e(k)$

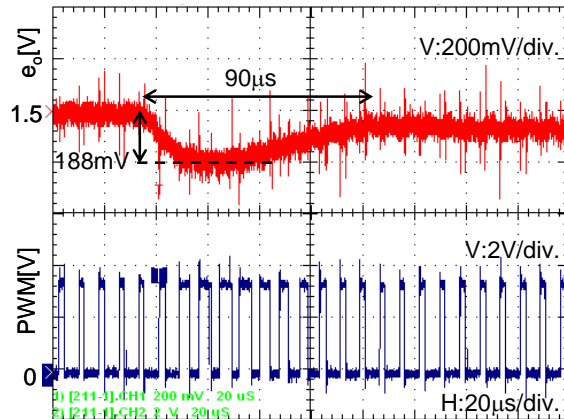
K_P : a proportional gain

K_I : an integral gain

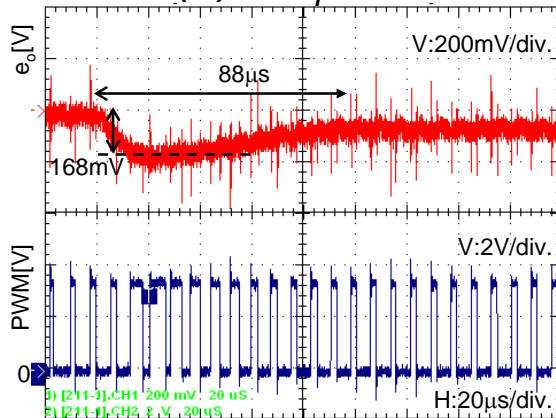
K_D : an derivative gain



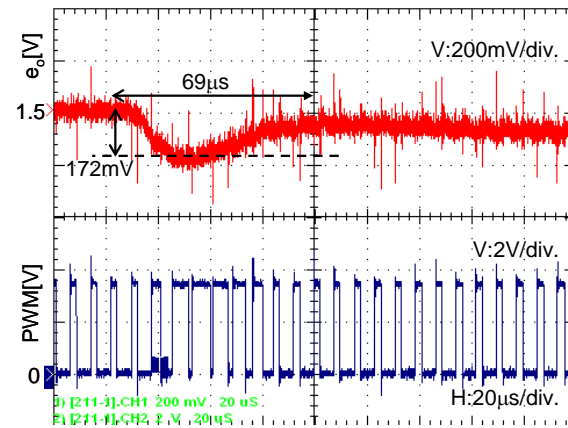
Experimental Results



(a) $K_p=5$



(b) $K_p=5, K_D=5$

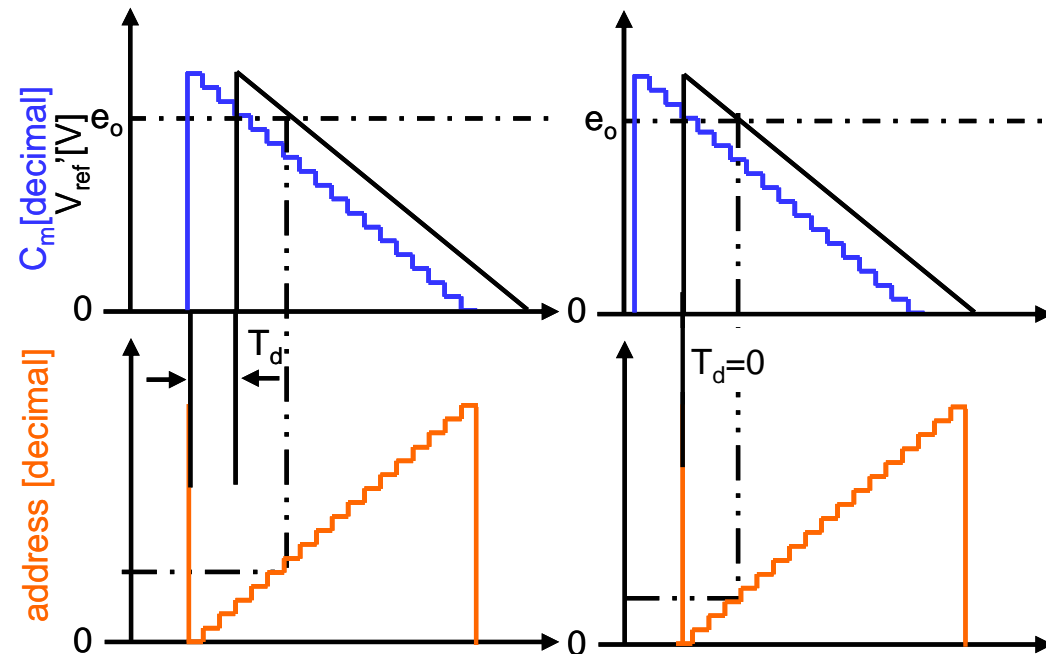
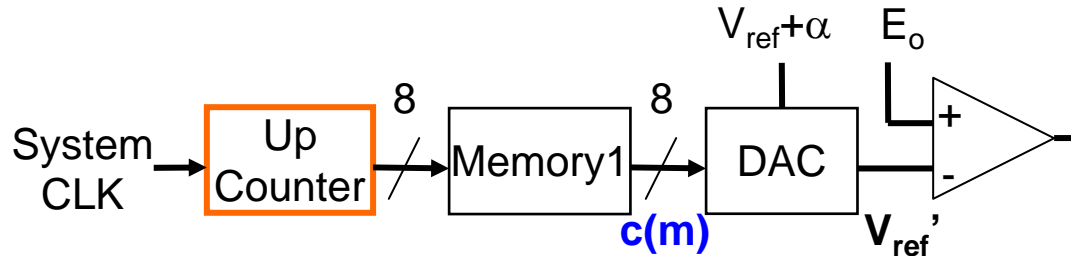


(c) $K_p=5, K_D=4, K_I=0.45$

Dynamic Characteristics
(0.5A → 3A)



The Propagation Delay Reduction



(a) Without compensation (b) With compensation

How to Reduce?

Shift forward for address
Information of memory1

Shift to memory : *shifting quantity*

$$\text{shifting quantity} = T_d \times f_{CLK}$$



The Propagation Delay Reduction

method

memory1

Shifting quantity: shifting memory address

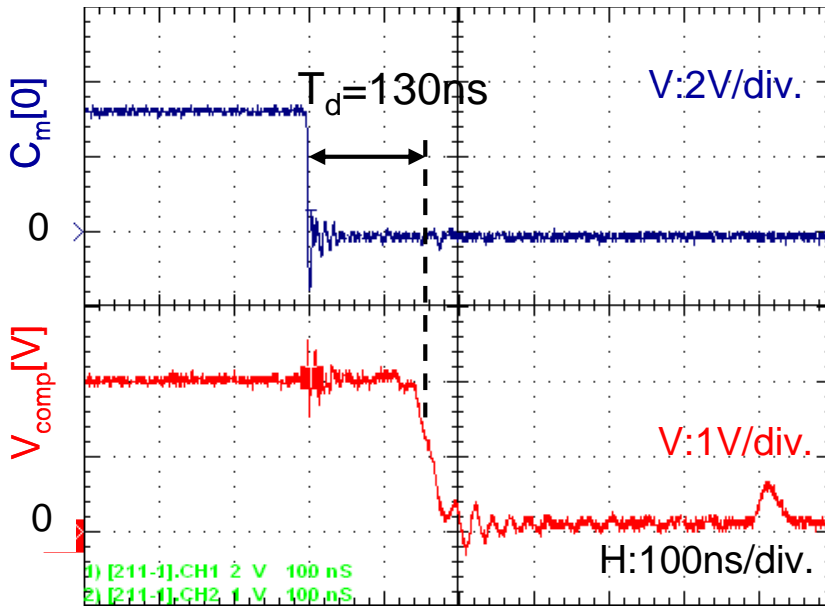
$$\text{shifting quantity} = T_d \times f_{CLK}$$

$$\text{shifting quantity} = 130[\text{ns}] * 33.3[\text{MHz}] \approx 4$$

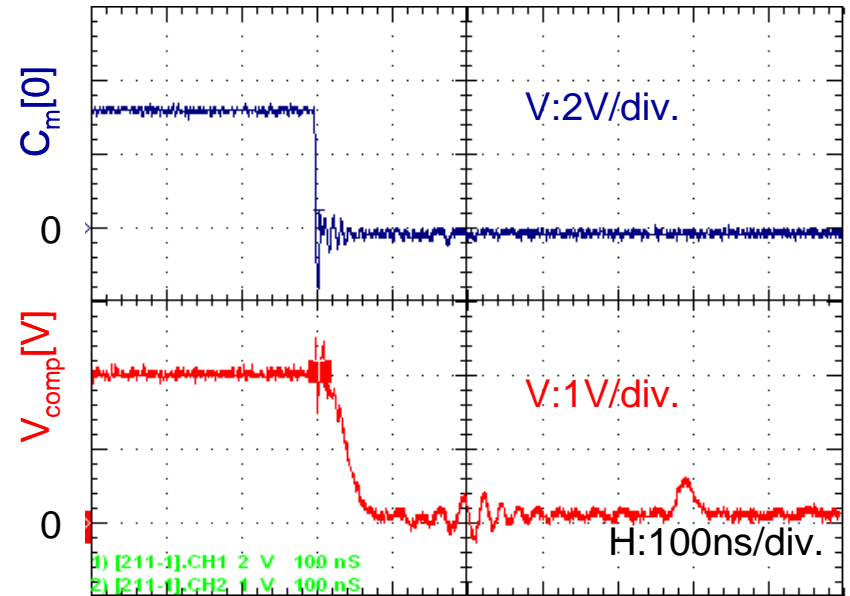
address	memory	Adjusted memory
0	255	251
1	254	250
2	253	249
3	252	248
4	251	247
5	250	246
6	249	245
⋮	⋮	⋮
⋮	⋮	⋮
250	5	1
251	4	0
252	3	255
253	2	254
254	1	253
255	0	252



Experimental Results



(a) Without Delay control



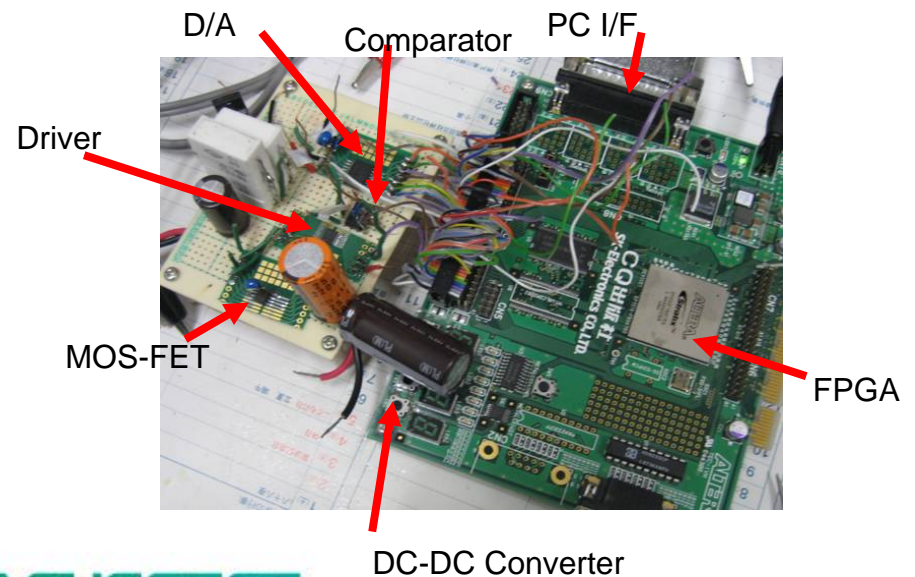
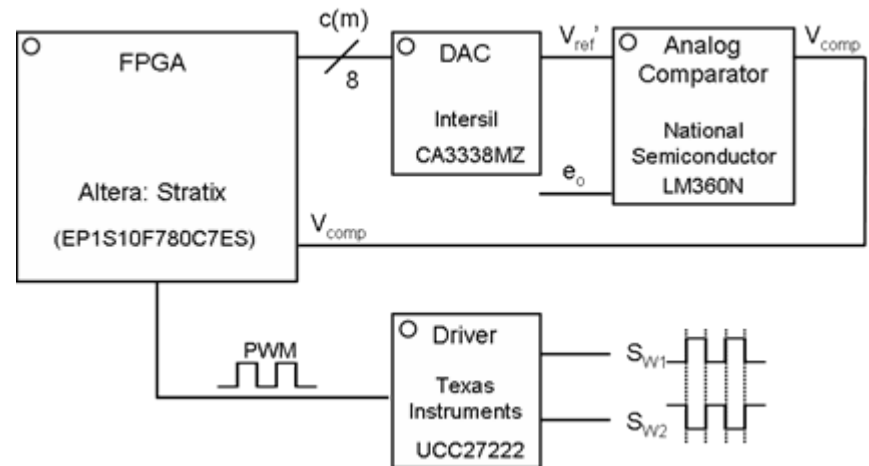
(a) With Delay control



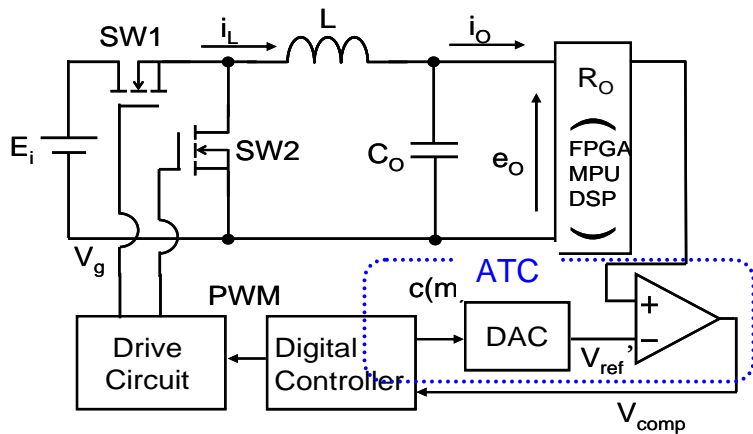
Prototype Circuit Experiments

Experimental Conditions

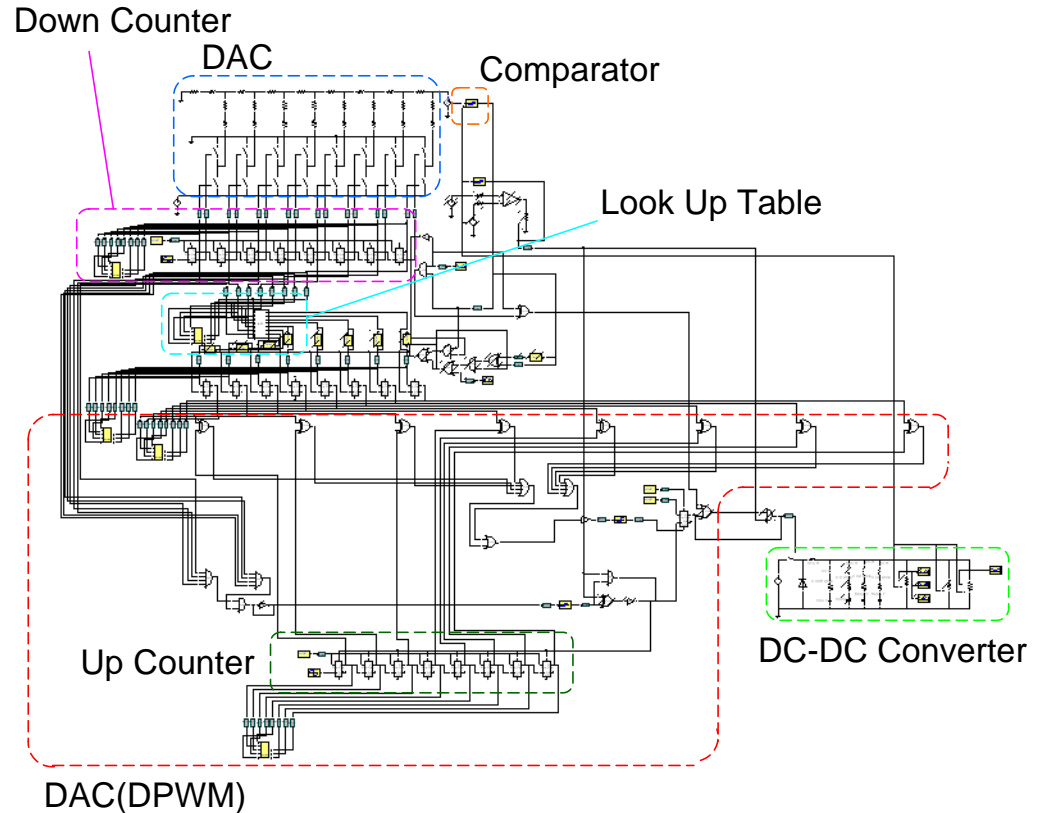
Input voltage E_i	2-8V
Output voltage E_o	1.5V
Output current I_o	0-5A
Switching frequency f_s	120kHz
Choke inductor L	$17\mu\text{H}$
Output capacitor C_o	$500\mu\text{F}$
Proportional gain K_p	1-5
Derivative gain K_D	1,3,5
Integral gain K_I	0.1-0.5
$V_{ref} + \alpha$	1.7V
System CLK	33.3MHz



Simulation Model (SIMPLORER)



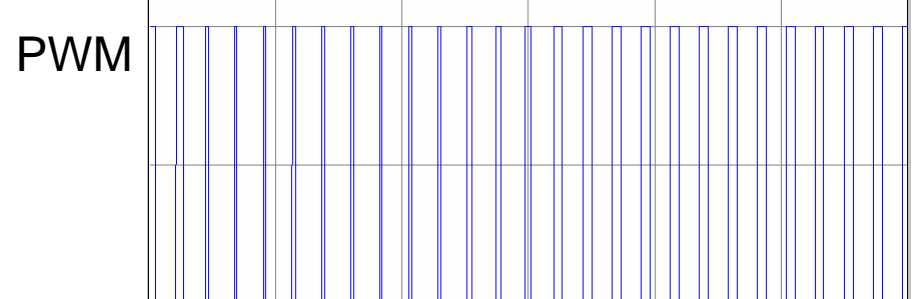
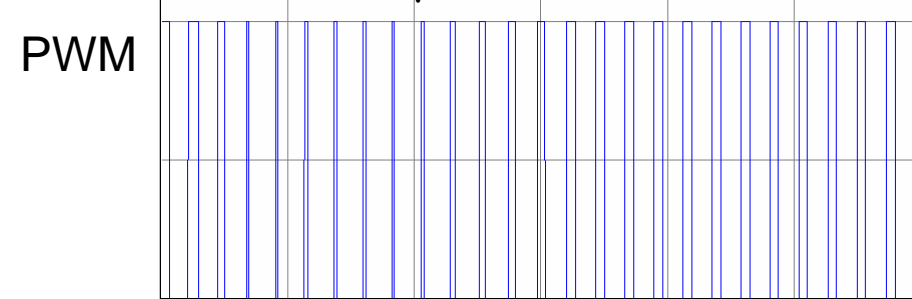
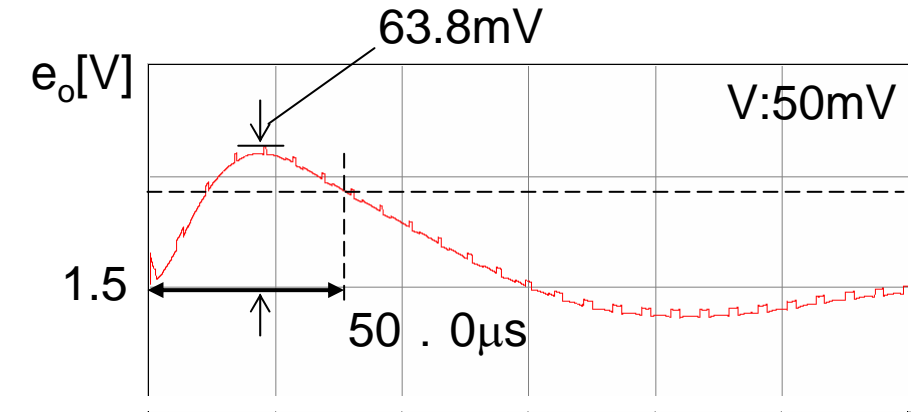
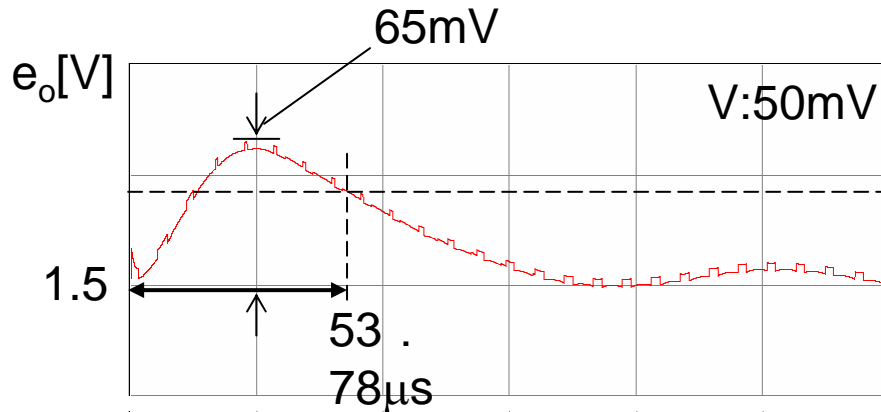
Experimental



Simulation Model



Simulation Results



H:33.3 μ s

H:33.3 μ s

(a) Without Delay control

(a) With Delay control

Load R_o was changed
Heavy Load $0.5\Omega \Rightarrow$ Light Load 3Ω



Conclusion

- The effectiveness of the proposed digital PWM for DC-DC converter without A/D converter is described.
- From the experimental results with prototype circuit, the total propagation delay time was suppressed to 30ns. And it was shown that the digital PID control was achieved within this time.
- We are planning to design a custom digital LSI of the control circuit with an appropriate size and cost, and to apply to high speed switching control or multi-phase control.

