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Abstract

Digital control SMPS (Switching Mode Power Supply) technology

For the overall energy saving, Switching Mode Power Supply (SMPS) achieved by various analog technologies began to apply digital technologies.

In first generation of Digital control SMPS, the partial digitalization based on hardware is achieved, and it provides the communication, high efficiency, easy correction using memory and so on as features of digital technology.

In second generation, the control of the switching power supply became possible by the software technology of processor (mainly DSP) base now. The advancement of the semiconductor process technology improve the processing speed of DSP, the performance gain of the A/D converter and also PWM are remarkable. Then, it has become an environment where the high-speed switching control by DSP can be applied easily.

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Digital control SMPS technology

(Switching Mode Power Supply)

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CONTENTS

a. Digital control in the generation
b. Feature of control DSC
c. PI control
d. Summary

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Transition of Digital SMPS

Separation & Supplementation from/to Analog SMPS

DSC for SMPS ; Full digital controll by Software
High speed A/D converter,
High resolution PWM,
High performance DSP

DSC to SMPS ; Digital control by Software,

Supplementation for Analog SMPS

(MPU) + Controller IC + Analog SMPS ;
PI control & Adjustability with limitation,

MPU or Sequencer + Analog SMPS ; On/Off control, Communication

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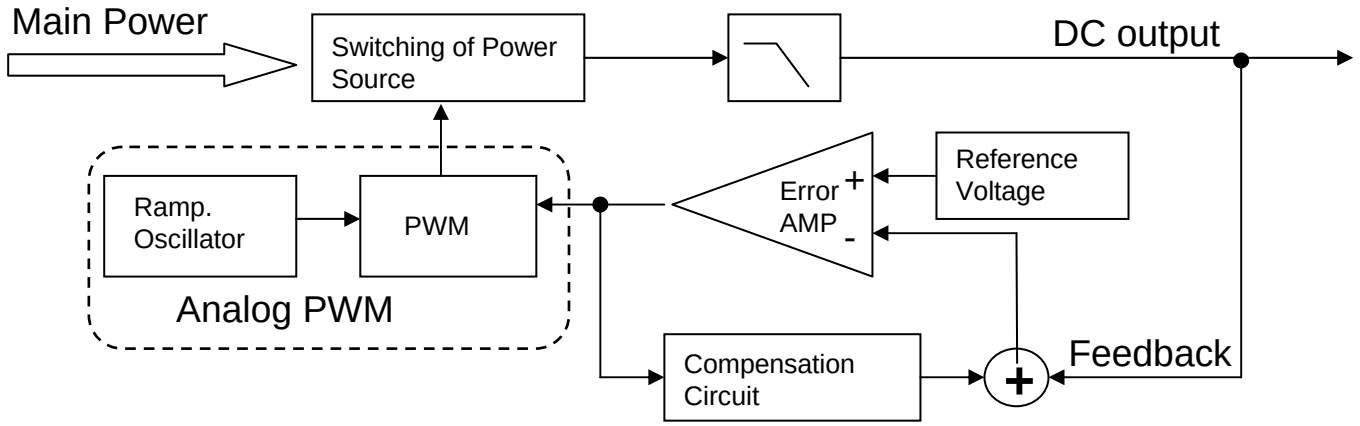
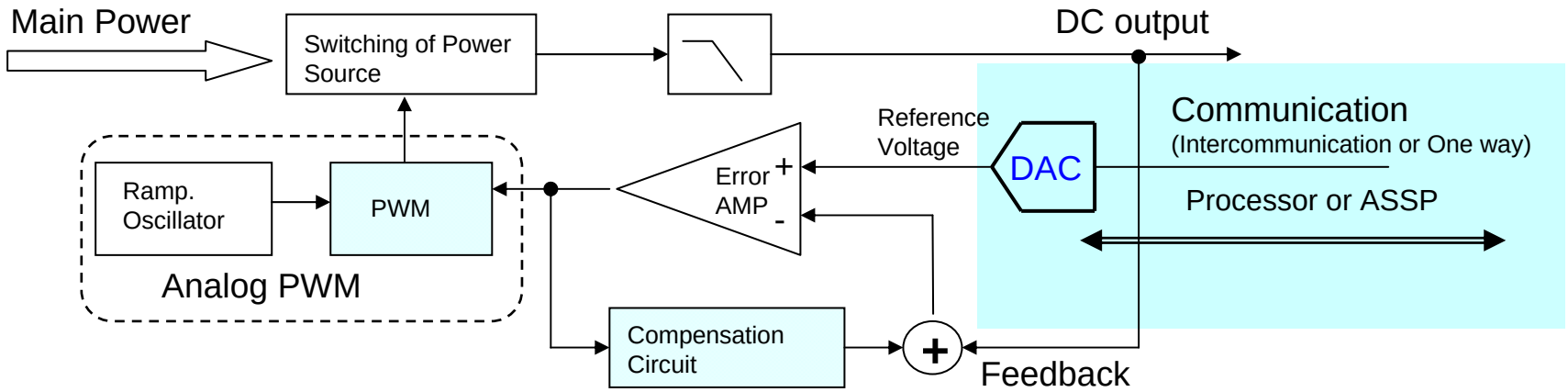
Analog & Digital Control in first generation

Analog control of DC-DC converter



Digital control in first generation of DC-DC converter



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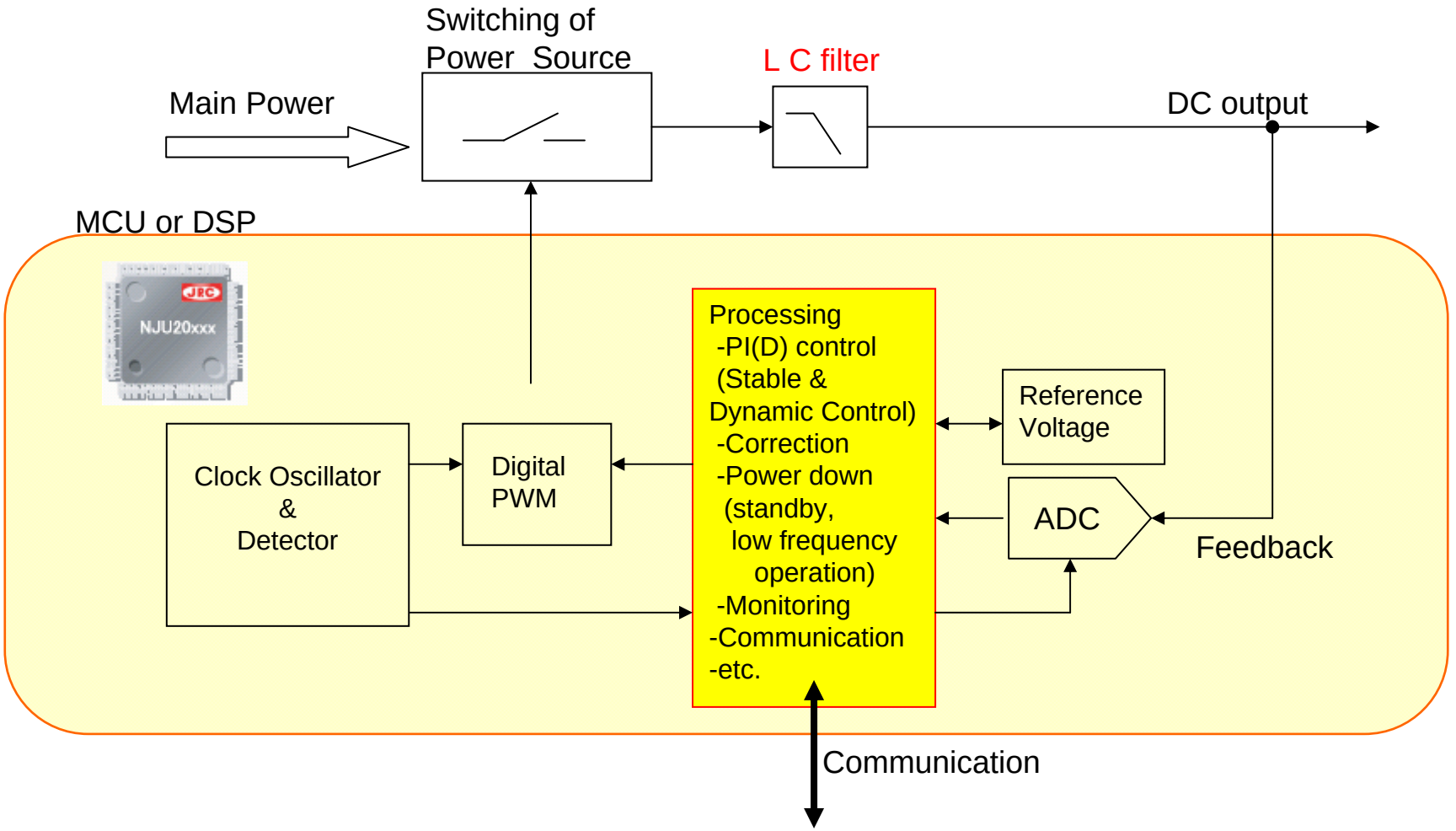
Digital control in second generation

Software control of processor (mainly DSP) base toward a full digital control

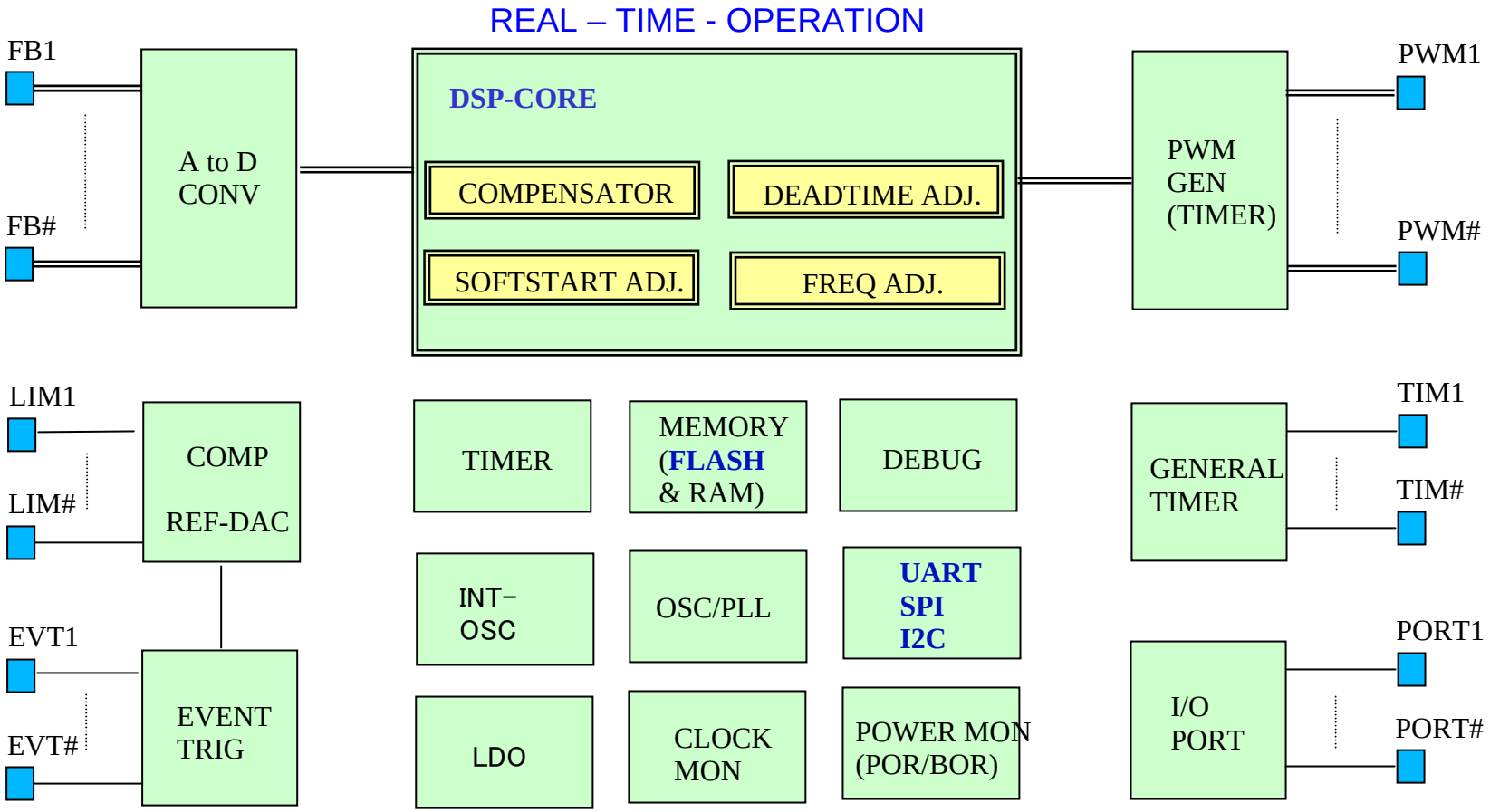


Digital control system example in second generation

Feedback control system by software operation on DSP

⇨ Full digital control by cooperated operation with software & hardware

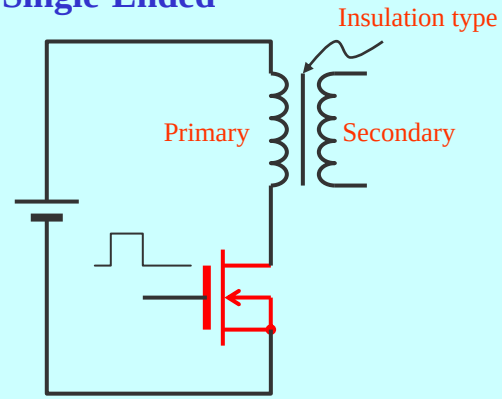
Both of high speed AD converter & high resolution PWM generator achieve the control in a cycle



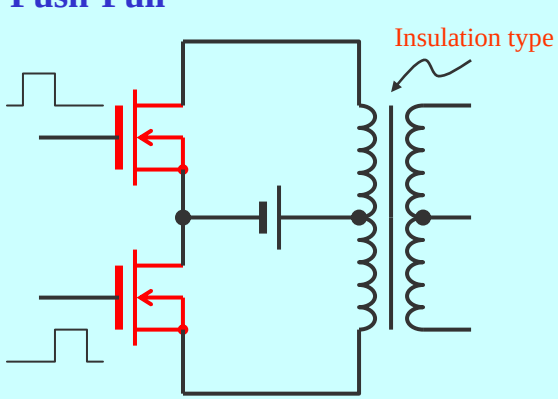
Circuit configuration of switching power supply

Applicable to AC - DC, DC – DC, insulation type, non-insulation, PFC (Power Factor Correction), and etc.

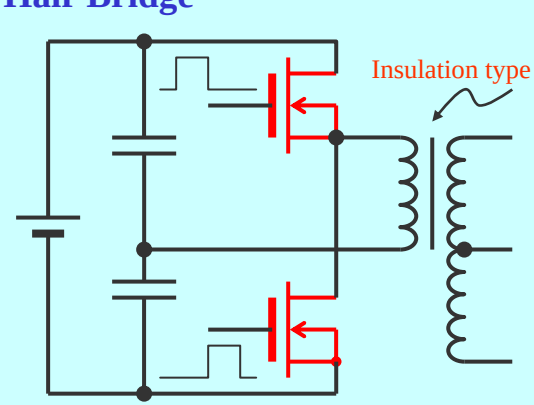
Single-Ended



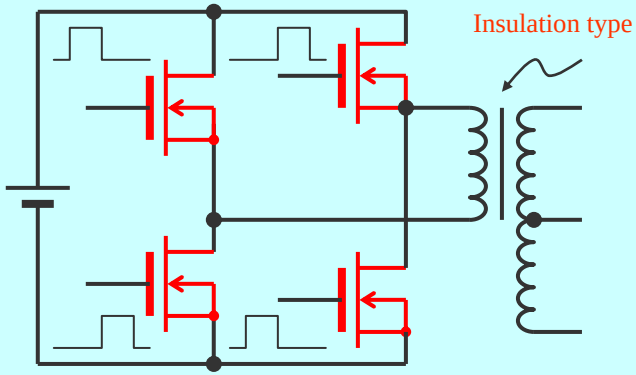
Push-Pull



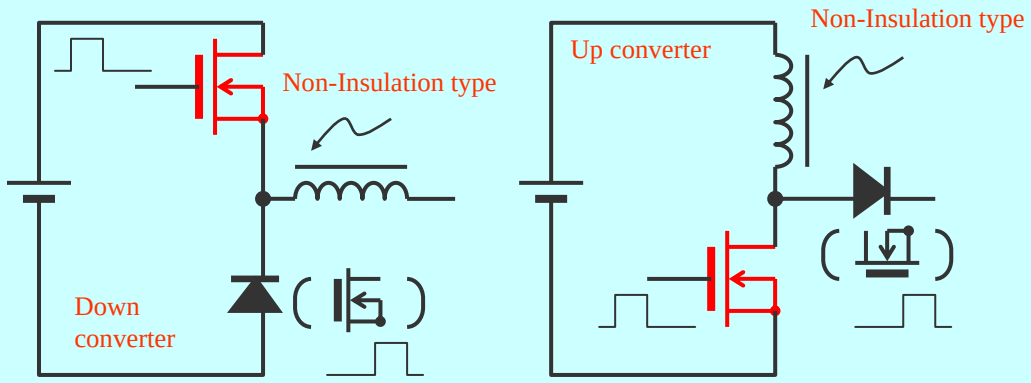
Half-Bridge



Full-Bridge



Chopper



•PFC (power factor correction)

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CONTENTS

a. Digital control in the generation

b. Feature of control DSC

c. PI control

d. Summary

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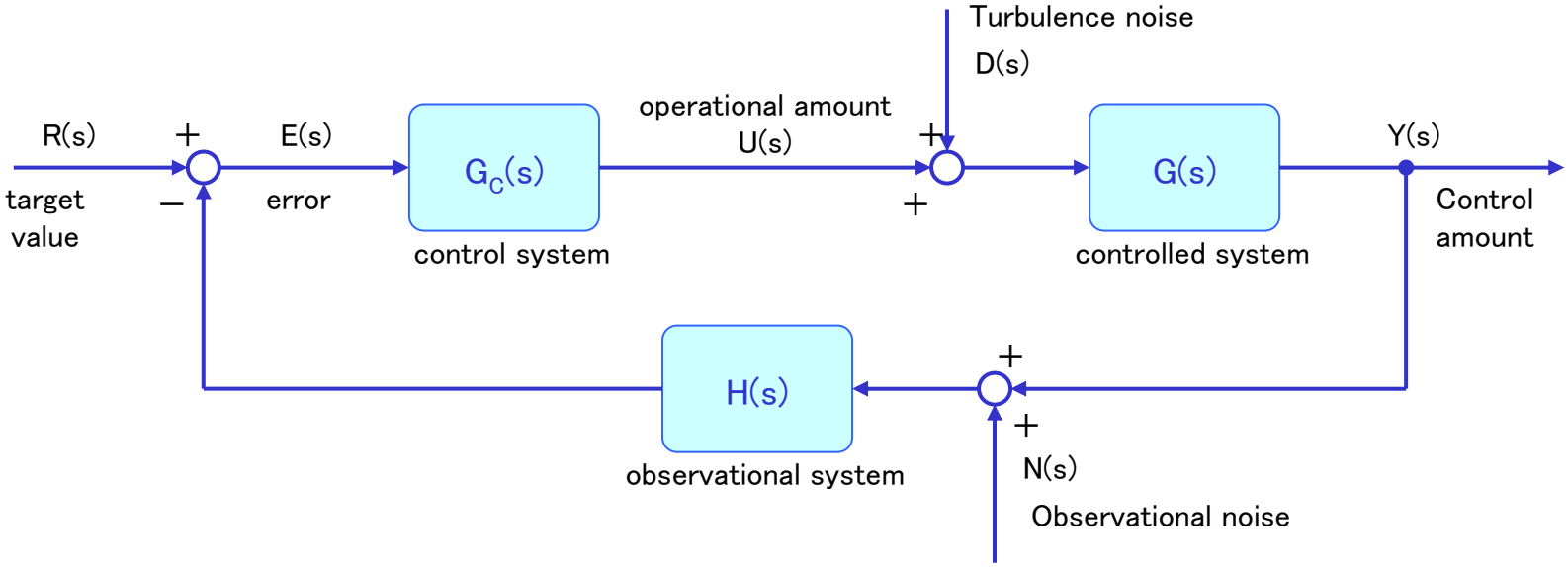
Feature of control DSC in designing process of SMPS

A, Selection of PWM minimum resolution
B, Correction of ADC
C, Design of PI control filter



$$Y(s) = \frac{G_C(s)\,G(s)}{1 + G_C(s)\,G(s)\,H(s)} R(s) + \frac{G(s)}{1 + G_C(s)\,G(s)\,H(s)} D(s) - \frac{G_C(s)\,G(s)\,H(s)}{1 + G_C(s)\,G(s)\,H(s)} N(s)$$

Transfer function ;
Target value – Control amount

Transfer function ;
Turbulence noise – Control amount

Transfer function ;
Noise – Control amount

Block diagram of a feedback control system

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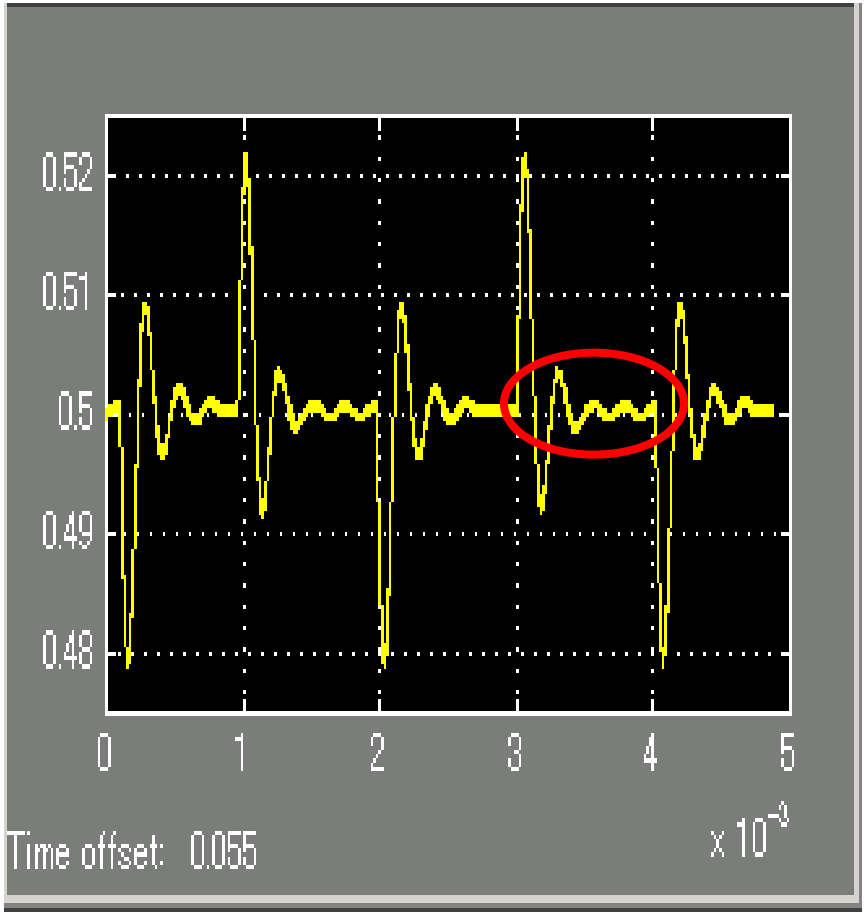
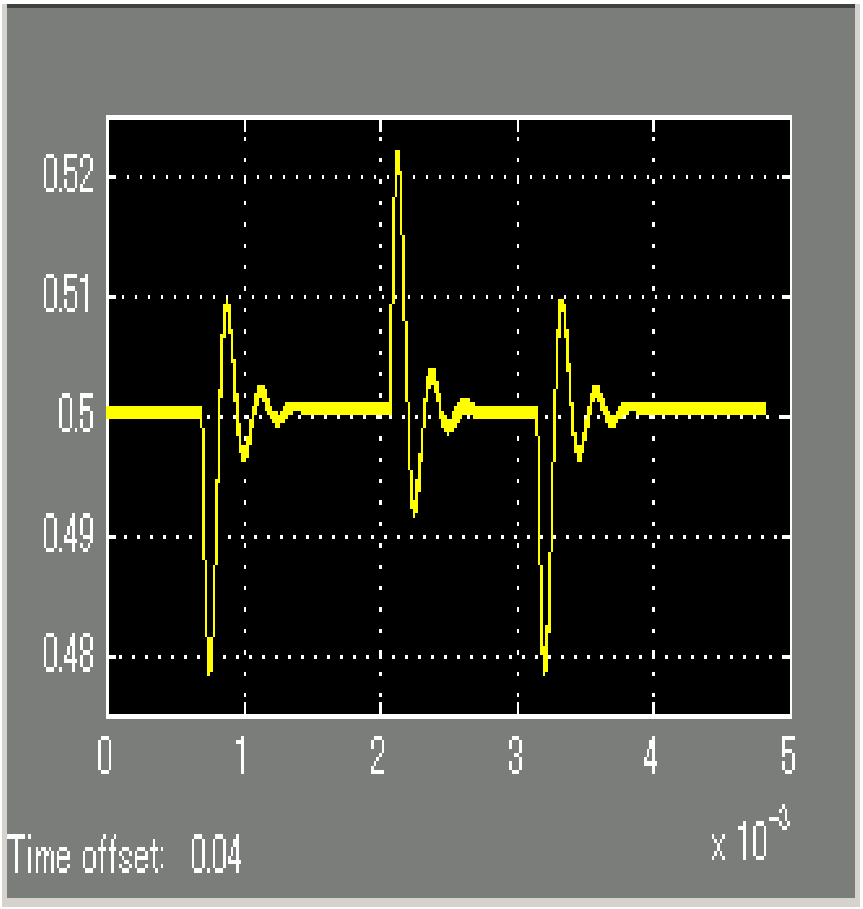
Influence of PWM minimum resolution

<10 bits resolution>



<16 bits resolution>



Step response

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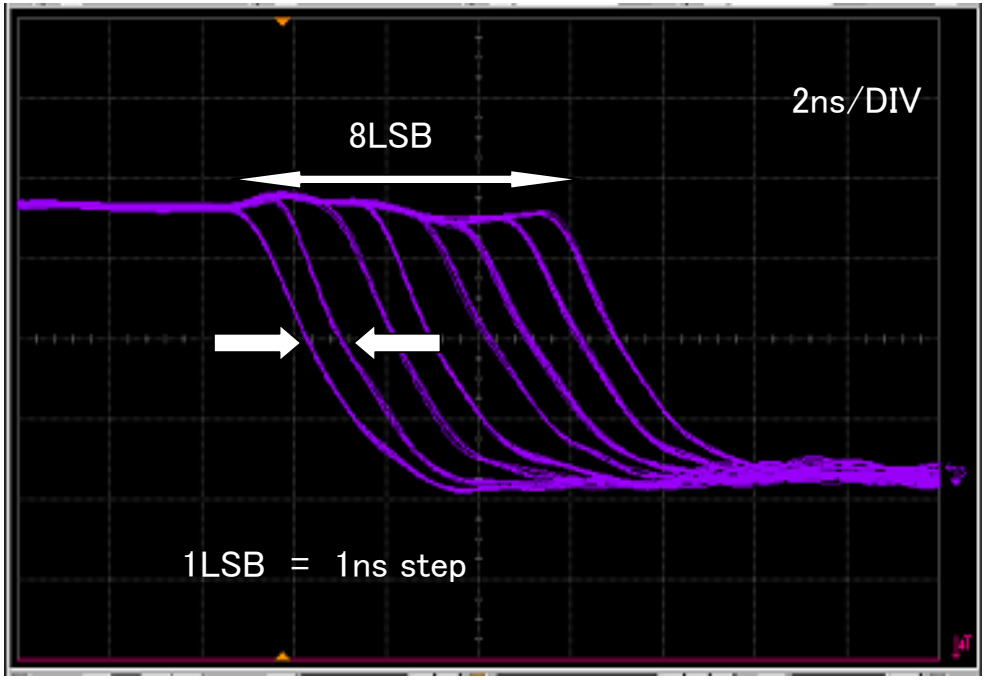
Feature of High Resolution PWM

High Resolution PWM

The transition time of the PWM waveforms depends on the accuracy of the reference clock (quartz oscillator, and ceramic resonator).

Moreover, the minimum resolution can be selected according to the permissible error independently from CPU clock frequency.



The minimum timing resolution of PWM is decided by the power source switching speed, and the amplitude resolution of the A/D converter.

The power MOS driver and its pre-driver must correspond to the performance of the PWM, to achieve the expected performance of SMPS.

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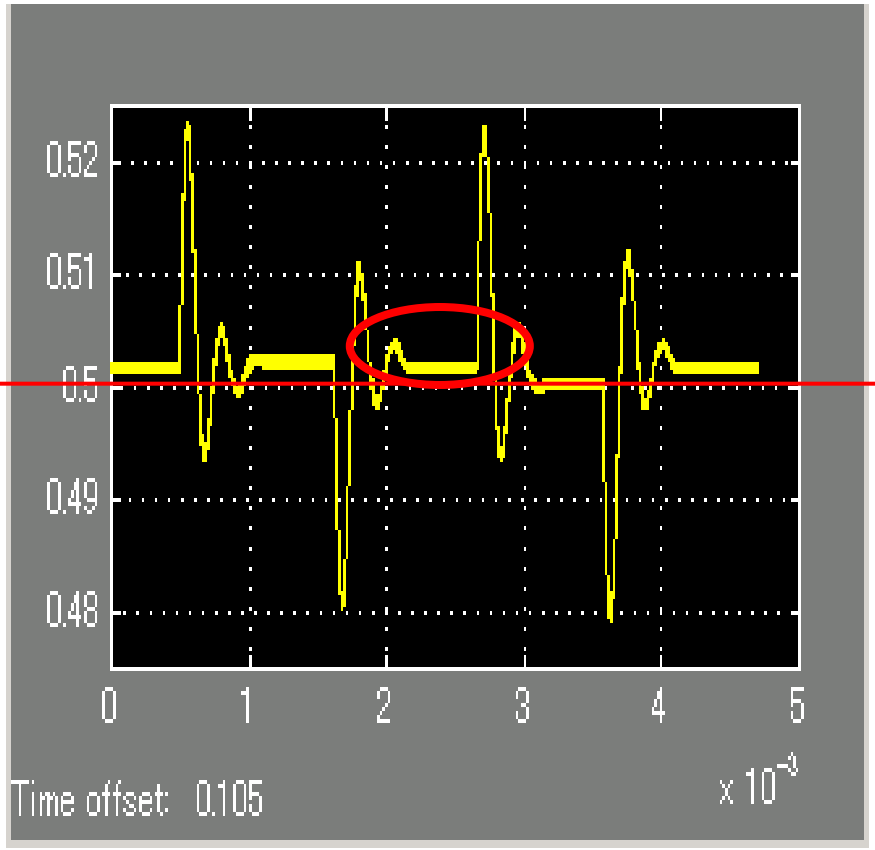
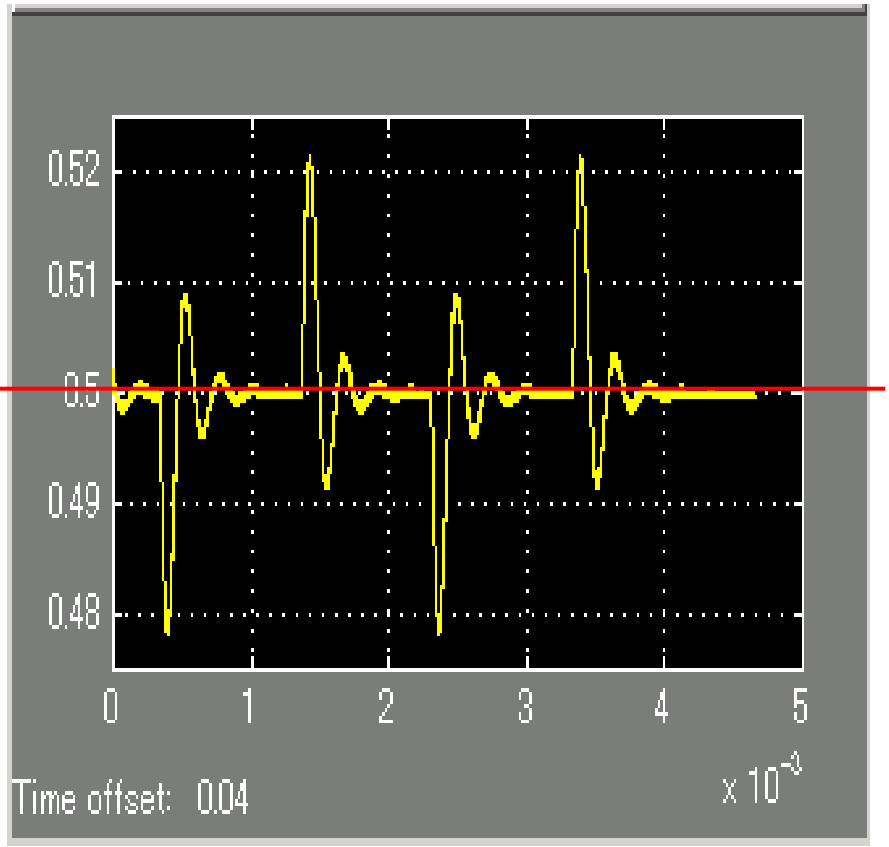
Influence of ADC resolution

Bouncing operation = Ripple

<8 bits resolution>



<16 bits resolution>



Step response

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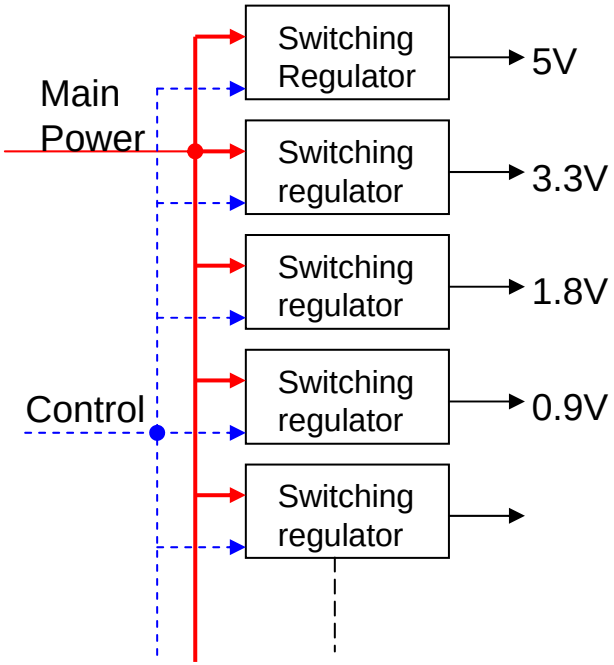
High speed A/D converter for multi-channel inputs

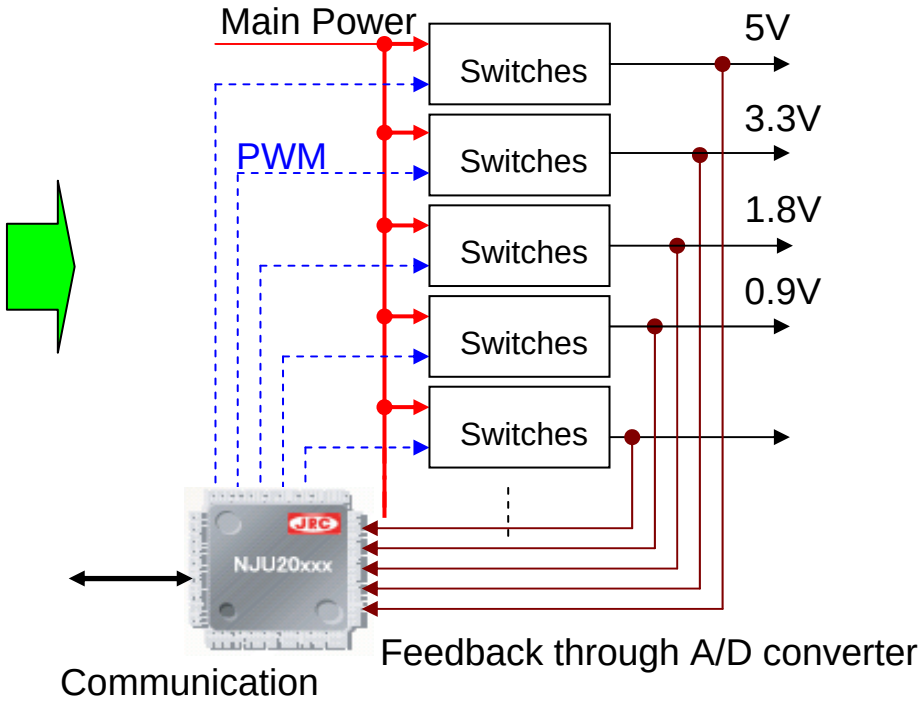
Analog type SMPS achieve the low cost and low power system in the application of single channel or few channels or a special requirement.

Digital control SMPS achieve the total power reduction at any time and conditions.
Key words;
Self power consumption, Number of output channels, Conversion speed of A/D converter, Processing speed, Dynamic control optimization, etc.)

Analog application



Digital application



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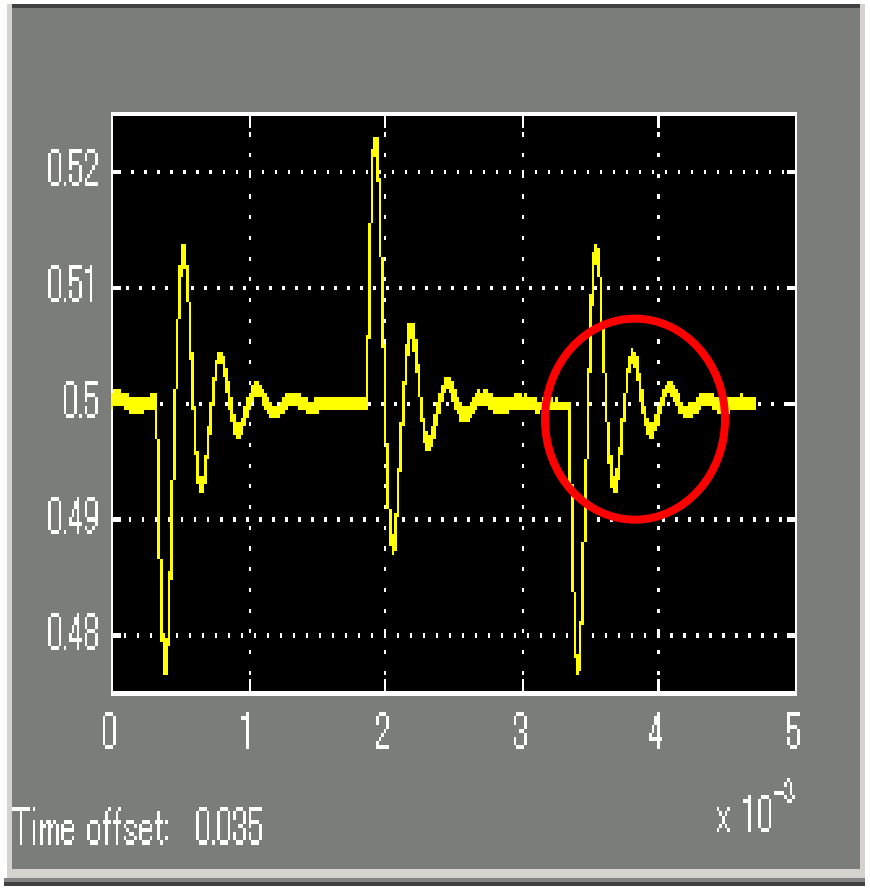
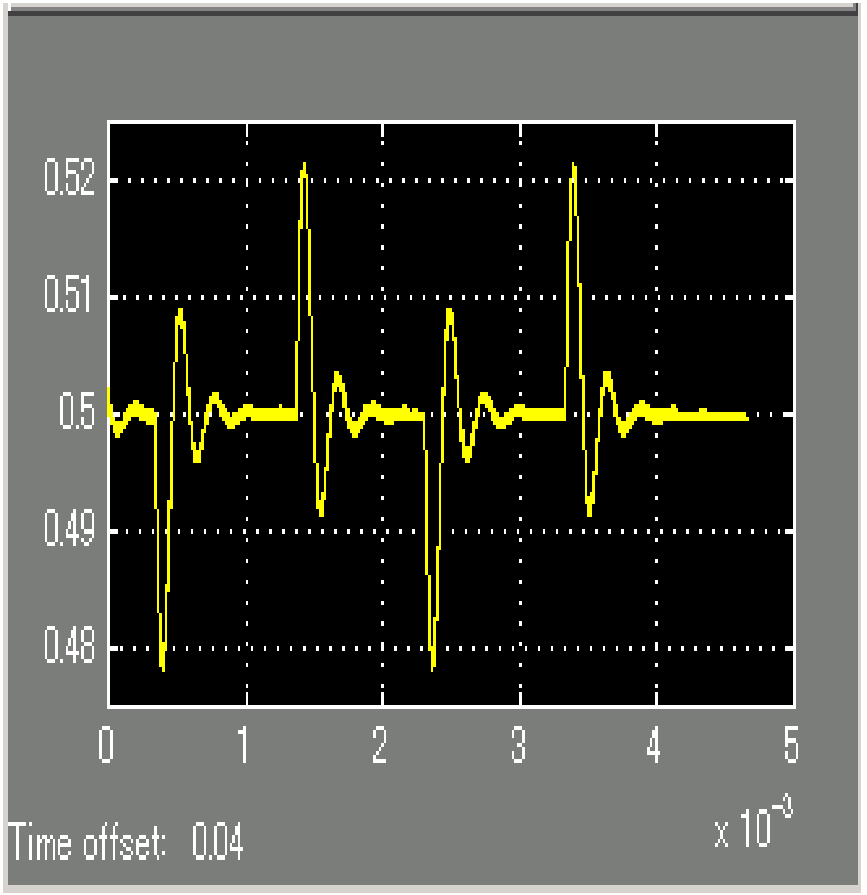
Influence of control delay

< 2 samples (cycle) delay >



< No control delay >



Step response

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CONTENTS

a. Digital control in the generation
b. Feature of control DSC
c. PI control
d. Summary

Transfer function of PI control

Step. 1 Linear Transfer function (continuous time) ; Laplace transform

$$PI(s) = K_P + \frac{K_I}{s}$$

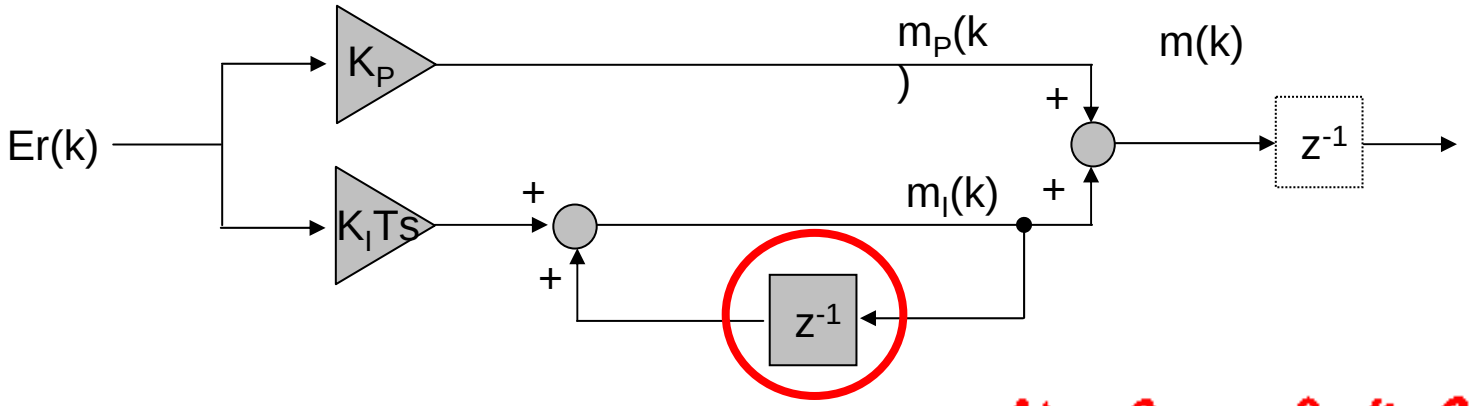
Step. 2 Difference equation on discrete time ; Z-transform

$$m_I(k) = K_I \cdot Ts \cdot Er(k) + m_I(k-1)$$
$$m(k) = m_P(k) + m_I(k) = K_P \cdot Er(k) + m_I(k)$$

; Backward Euler

$$m_I(k) = K_I \cdot Ts \cdot \{Er(k) + Er(k-1)\}/2 + m_I(k-1)$$
$$m(k) = m_P(k) + m_I(k) = K_P \cdot Er(k) + m_I(k)$$

; Trapezoidal(Tustin)



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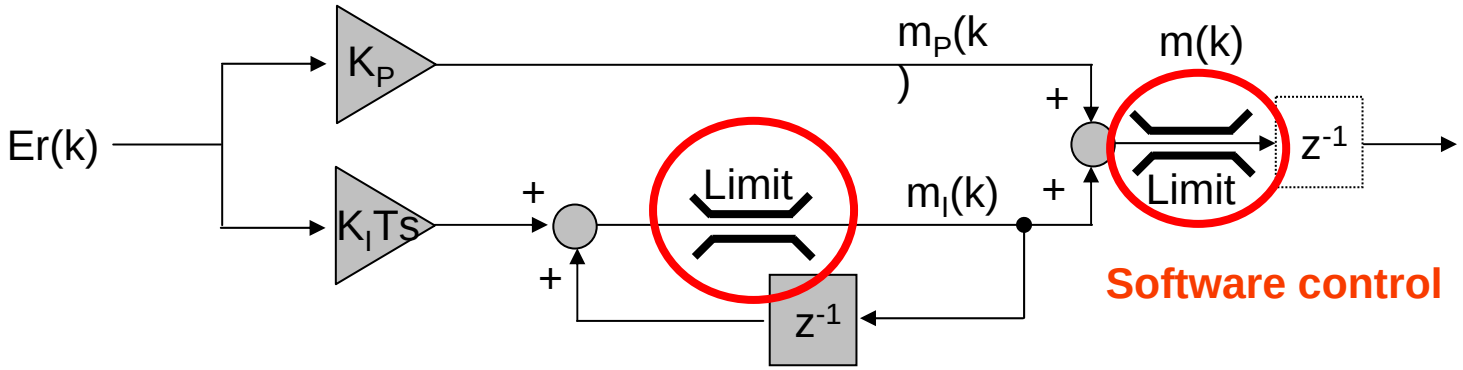

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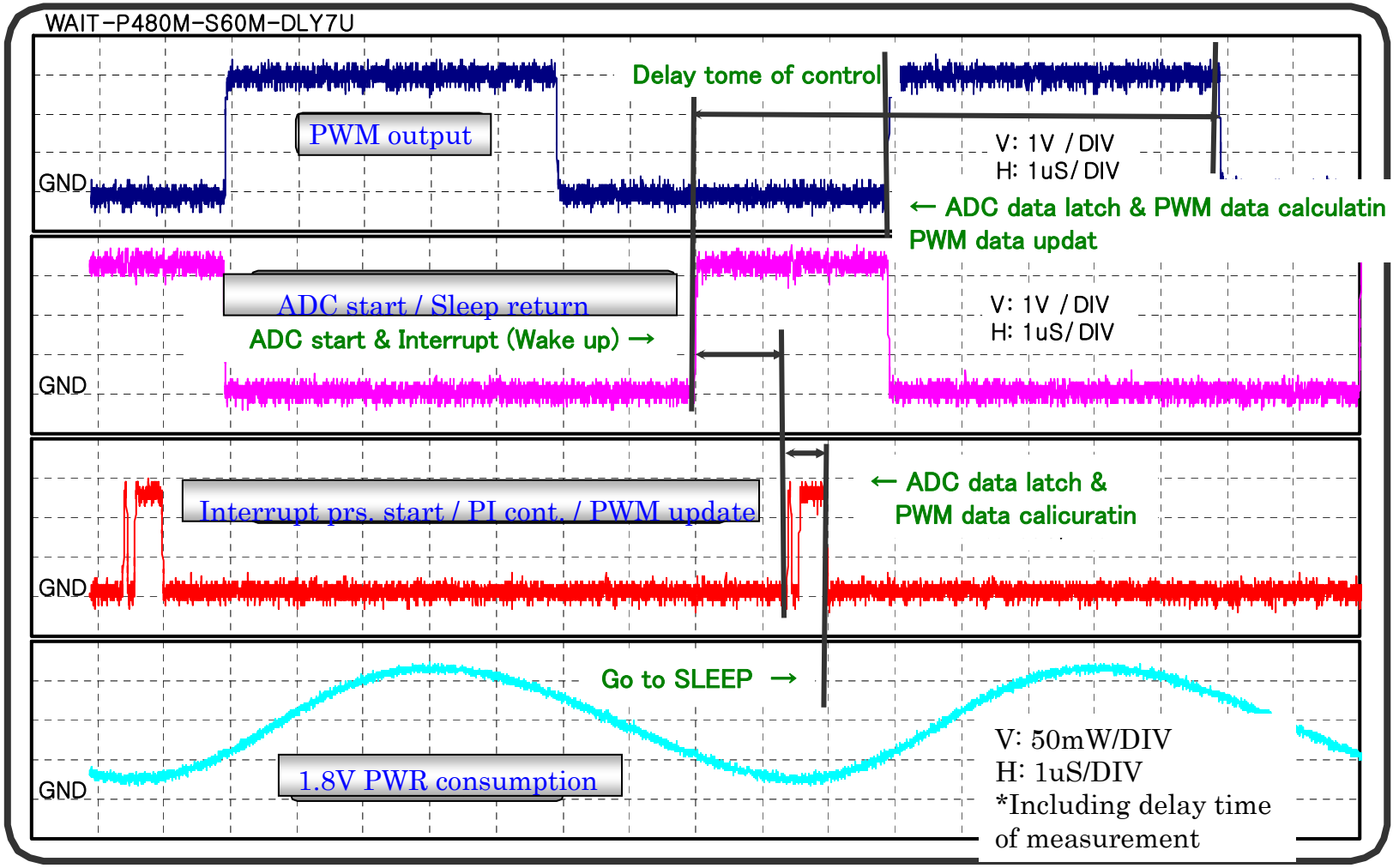
Embodiment of PI control

Improvement of power consumption and control delay time.



PWM minimum resolution : 1.0ns, System clock frequency : 60MHz, Sleep mode : WAIT

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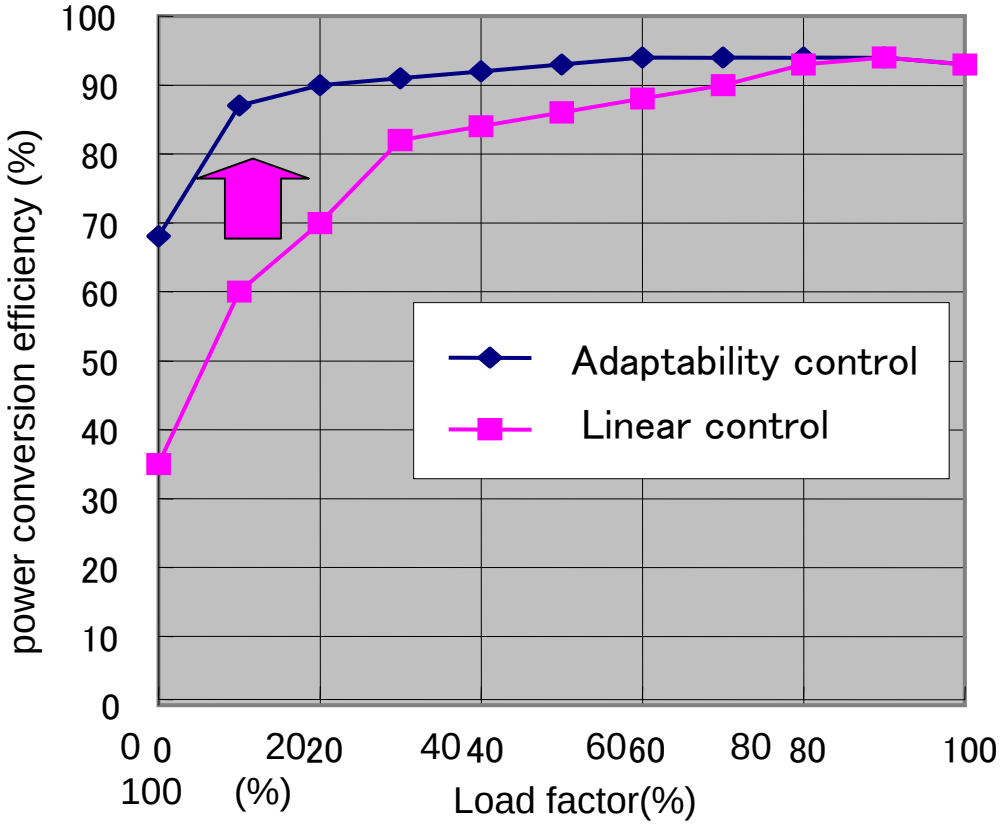
Adaptability of load change
total power conversion efficiency

Adjustment to become a maximum effect by the rated dissipation of the power supply circuit.



The black line : Control for maximum effect at the rated dissipation of the power supply circuit.

The red line : Adaptability control corresponding to the change of load electric power.

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CONTENTS

a. Digital control in the generation
b. Feature of control DSC
c. PI control
d. Summary

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Advantages & Disadvantages of Digital power supply

Miniaturization, high efficiency, optimization (topology) and communication
for engineer, supplier, system, user and *the earth*

Advantages of digital control power supply.

1. Miniaturization and reduction of parts in surrounding
   ⇒ space & cost reduction , higher reliability, expanding life, etc.
2. High efficiency : Advanced technology & optimization corresponding to the load change by dynamic software control technology . (topology control for dynamic change between loop filters)
3. High accuracy : Numeric & logical operation by software unrelated to the characteristics of parts.
4. Long life, and the high stabilization (There is no secular distortion).
5. Hardware standardization : Product development and variation depending on firmware. Development speed improvement (application of the best control method).
6. The mass production quality improvement: Smaller dependency to parts in surrounding.
7. Various corrections and automatically compensation : Temperature, part difference, voltage, etc.
8. Accumulation of know-how of control software, and its protection.
9, Communication : Status monitor, data logging, function upgrade, system cooperating operation , etc..

Disadvantages of digital control power supply.

1. Non available to higher switching frequency(>= 1MHz)
2. External FET driver
3. Power consumption of DSC
4. Cost of DSC
5. Inexperienced software design

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Thank you very much
for your attention.

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