EMI Reduction by Analog Noise Spread Spectrum In Ripple Controlled Converter

Yasunori Kobori, Taifeng Wang*, Nobukazu Tsukiji
Nobukazu Takai, Haruo Kobayashi

National Institute of Technology, Oyama College
Gunma University

JAPAN

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Outline

- Introduction
- Ripple Controlled Converter and Spread Spectrum
- Spread Spectrum with Analog Noise Generator
- Ripple Converter with Analog Noise Modulation
- Conclusion

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

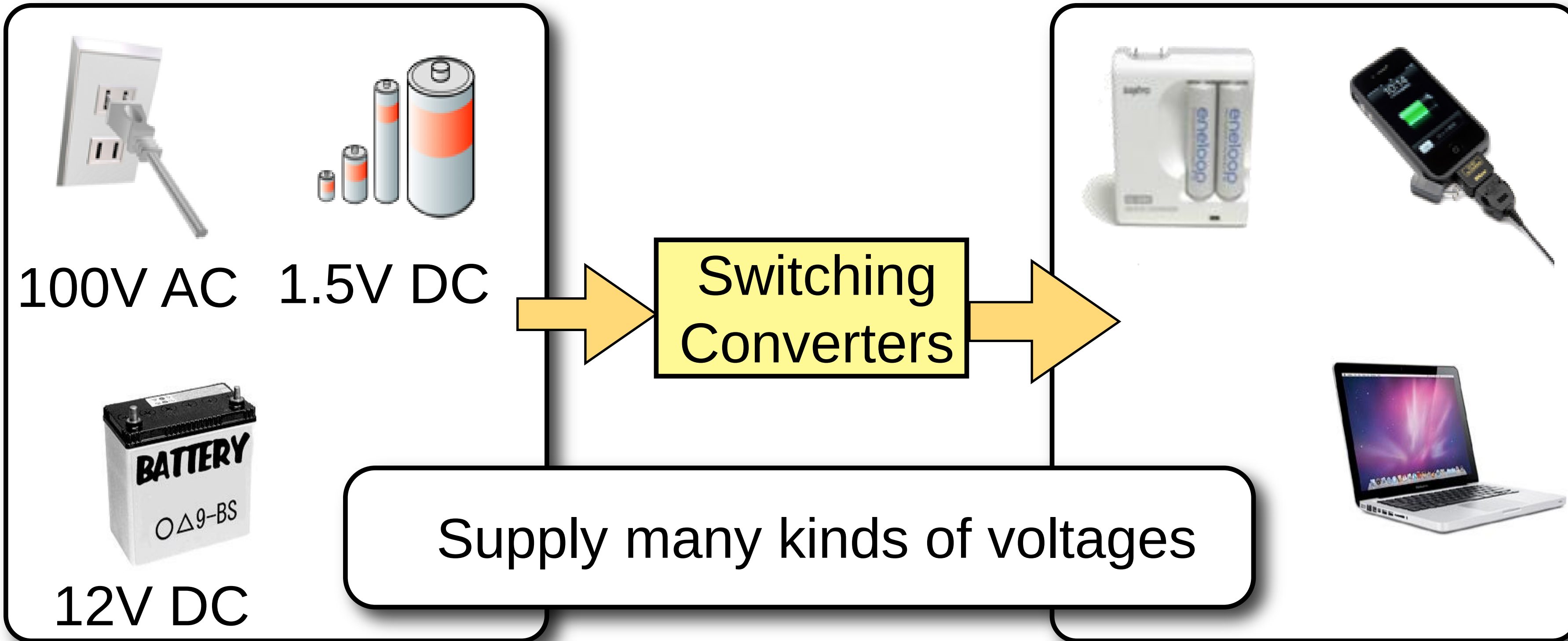
Outline

- Introduction
- Ripple Controlled Converter and Spread Spectrum
- Spread Spectrum with Analog Noise Generator
- Ripple Converter with Analog Noise Modulation
- Conclusion

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Research Background



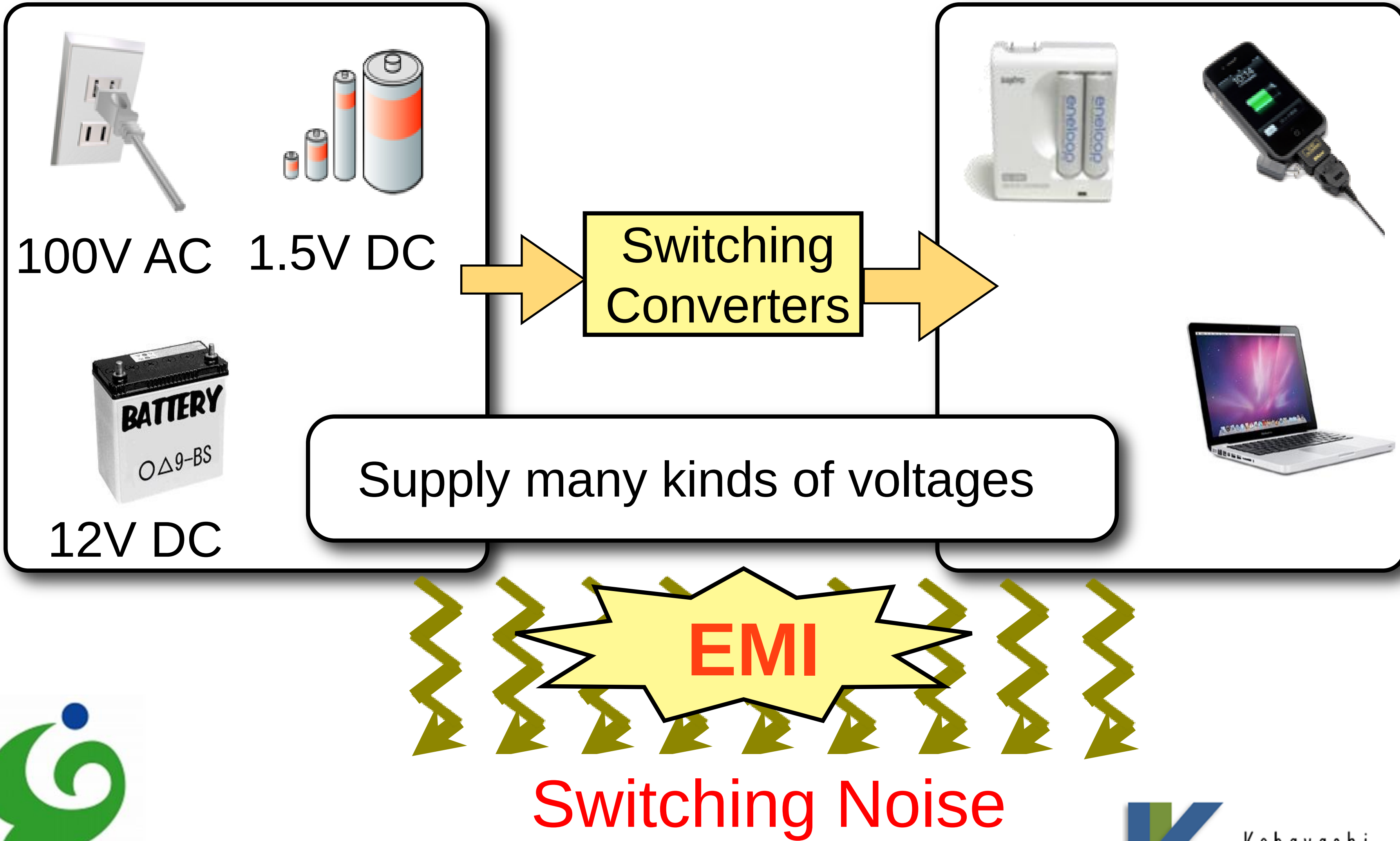
- 5.0 V, 4.2 V, 3.5 V,
- 2.5 V, 1.2 V etc.

● Many switching converters in equipment

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

EMI Issues



群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Research Objective

- Ripple controlled switching converter
  - fast transient response
  - small circuitry
  - No clock, No saw-tooth signal generator

⇩

Attractive

- Research Objective

  EMI reduction of ripple controlled converter

- Our Approach

  New spread spectrum method with pseudo analog noise

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

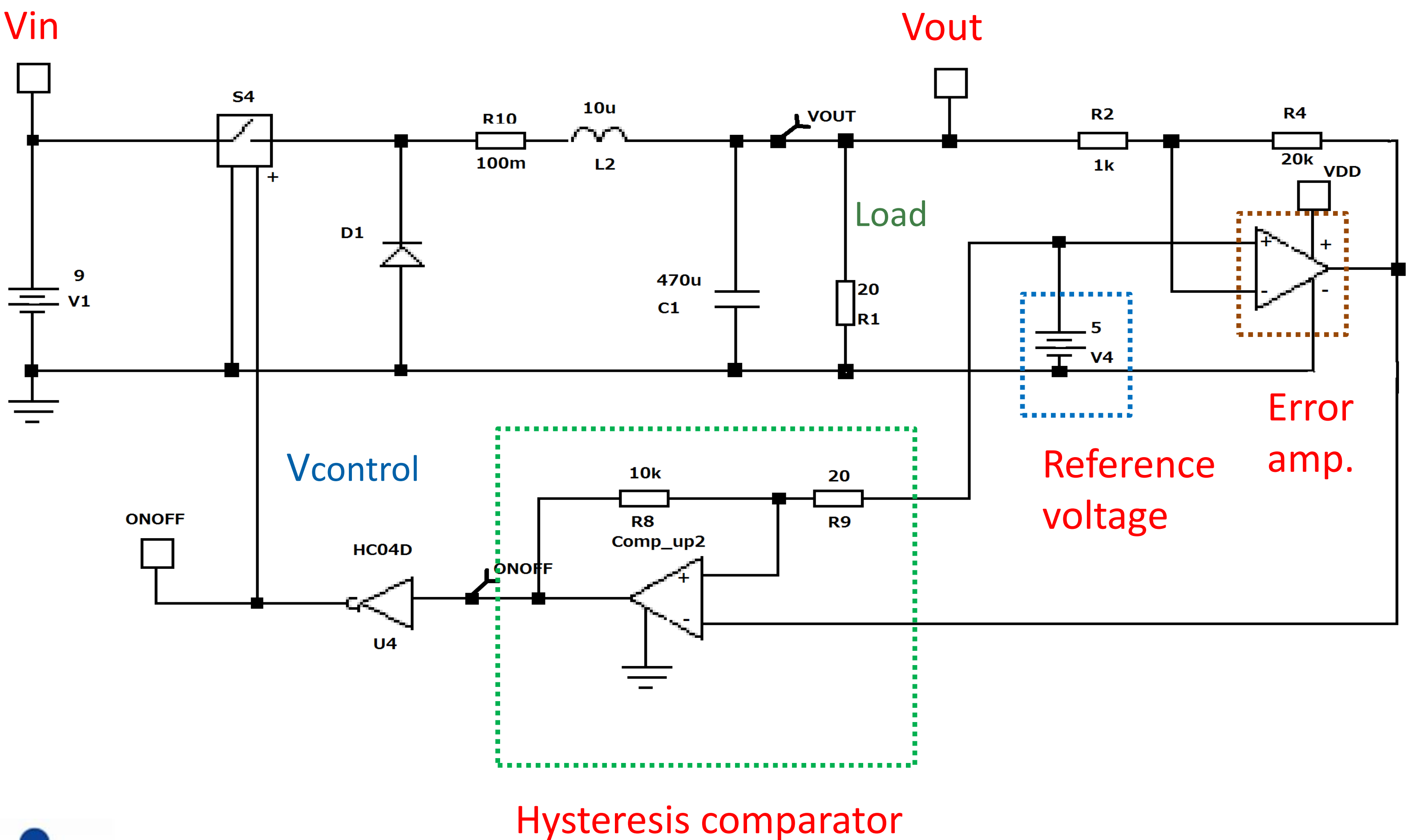
Outline

- Introduction
- <u>Ripple Controlled Converter and Spread Spectrum</u>
- Spread Spectrum with Analog Noise Generator
- Ripple Converter with Analog Noise Modulation
- Conclusion

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Conventional Rippled Controlled Converter (Configuration)

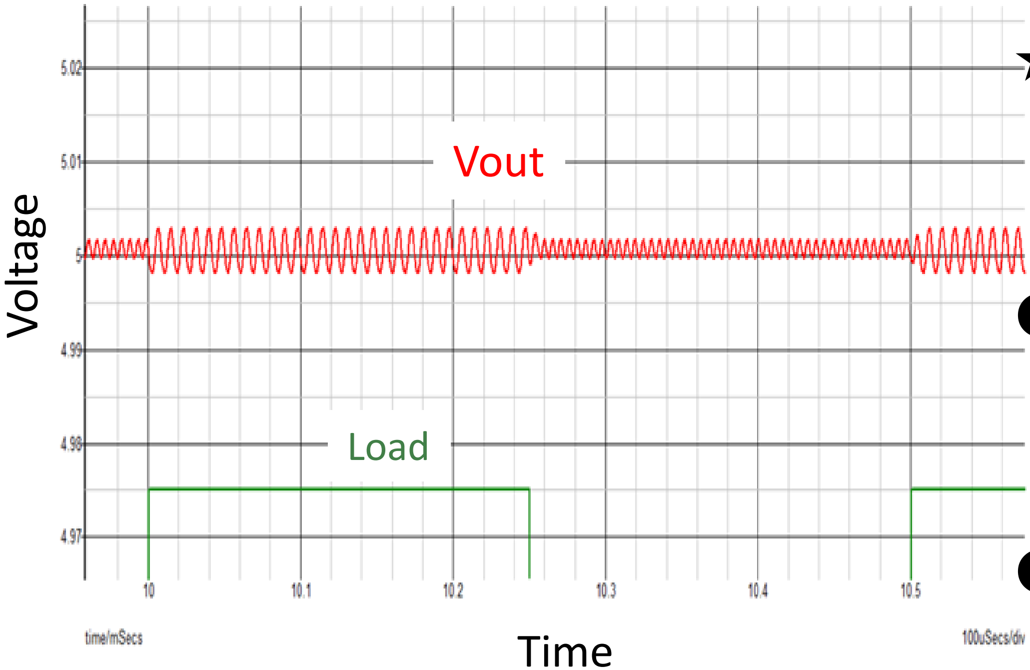


Hysteresis buck converter

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Ripple Controlled Converter Simulation (Time Domain)



Output voltage ripple and step response

★ Simulation Results

- Hysteresis level : Set to 20mV
- Frequency of the control pulse

  ⇓

  120k to 180kHz
- Output voltage ripple

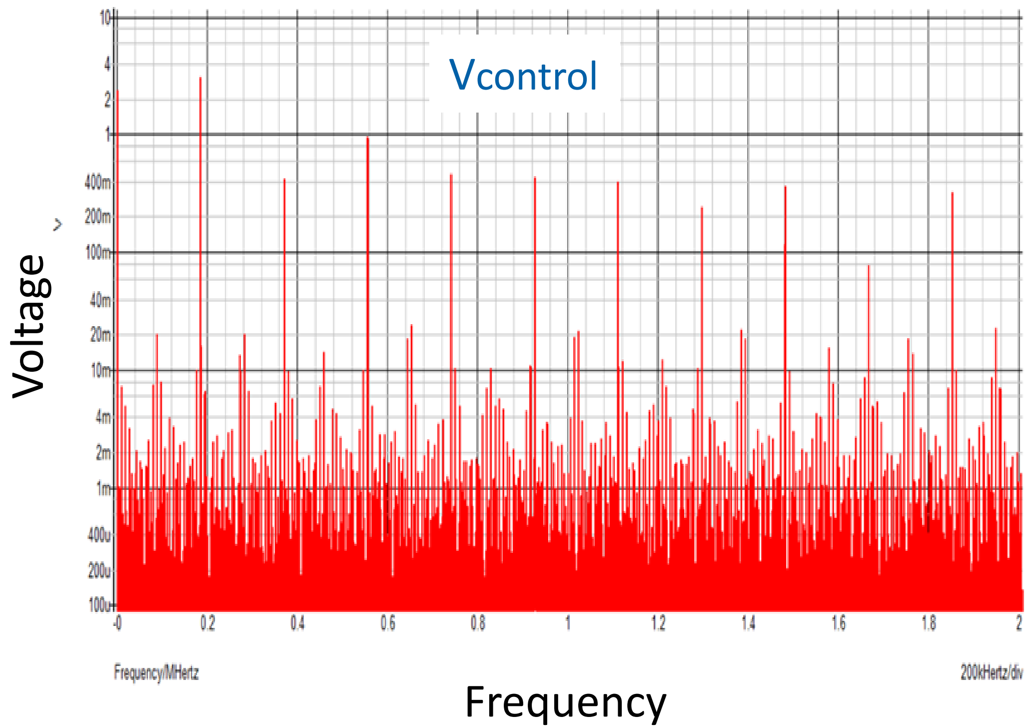
  ⇓

  Less than 5 mVpp
  (0.1 % of the output voltage)

群馬大学 GUNMA UNIVERSITY

Kobayashi Laboratory

Ripple Controlled Converter Simulation (Freq. Domain)



★ Simulation Results

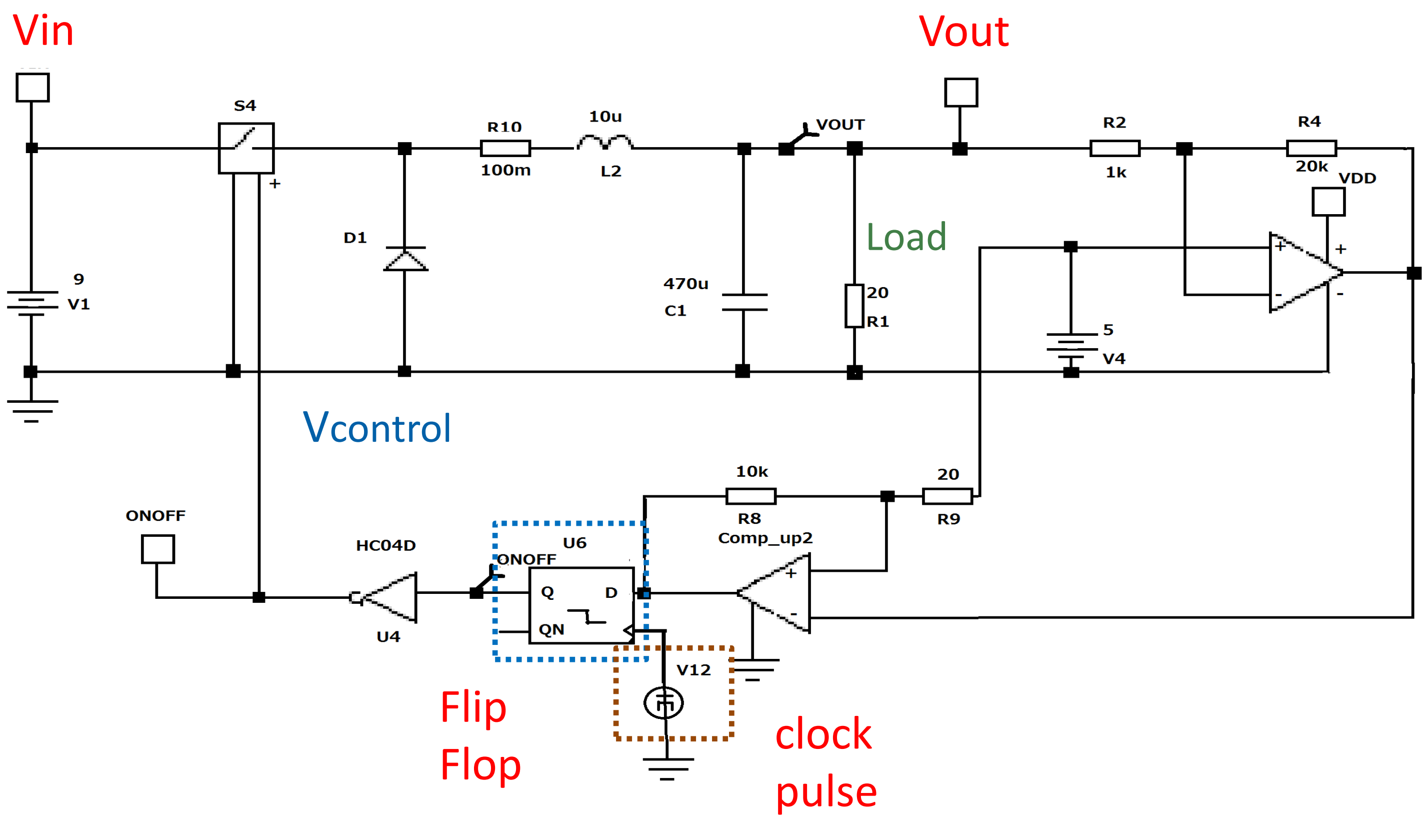
The highest peak level of 3V
at frequency of 185kHz

Simulated spectrum of the switching pulse
of the conventional ripple controlled converter

群馬大学
GUNMA UNIVERSITY

Kobayashi
Laboratory

Synchronized Ripple Controlled Converter (Configuration)



Switch (S4) control signal is synchronized with clock pulse.

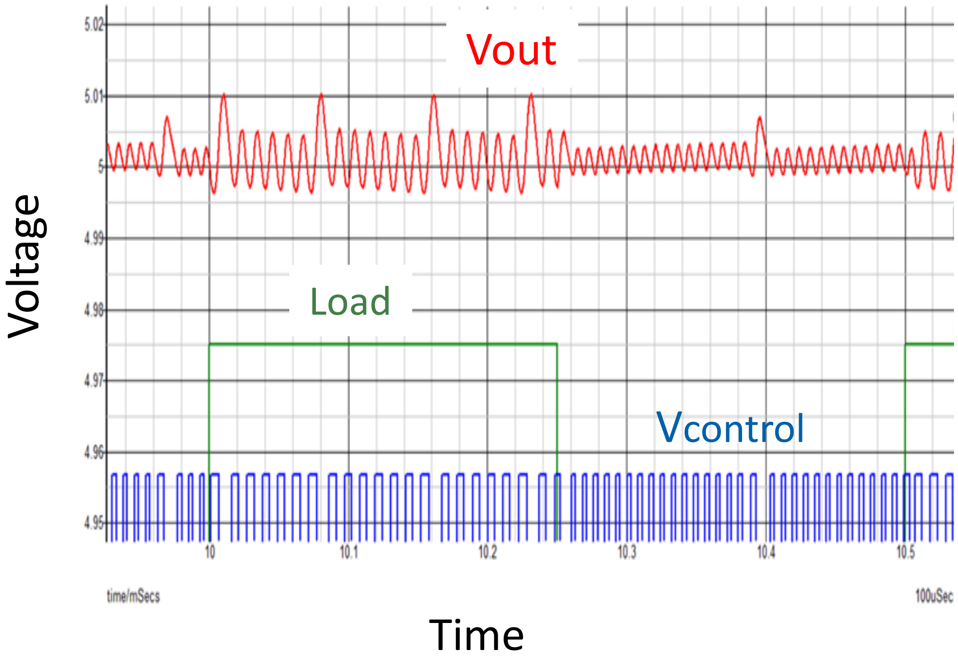
Stable operation

EMI problem

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Synchronized Ripple Controlled Converter (Time Domain)



★ Simulation Results

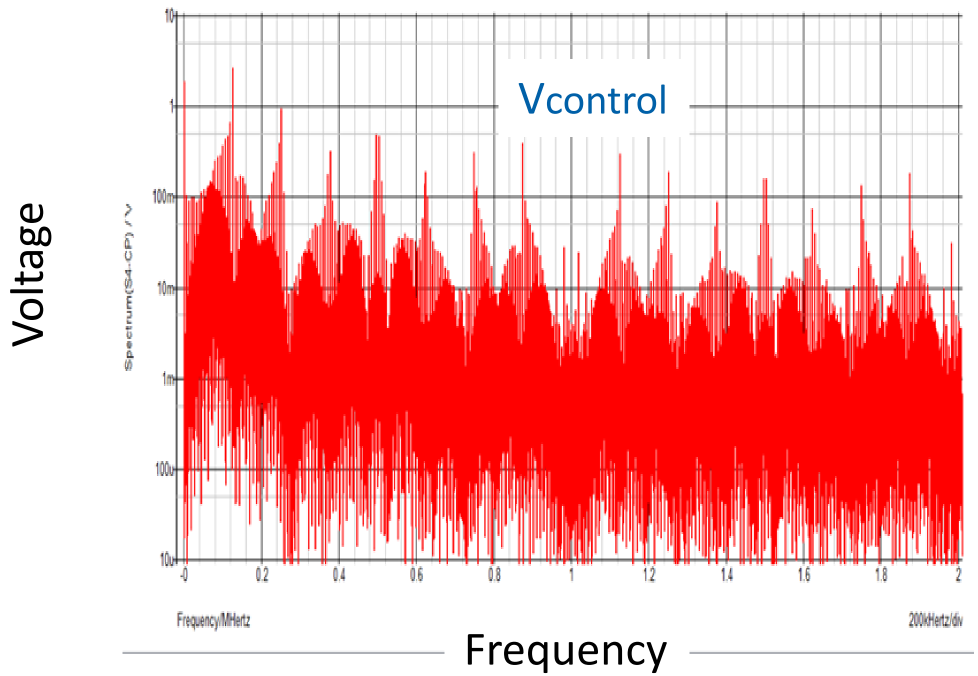
Ripple level is a little bit large (about 13 mVpp) when the output current is changed to 1.0 A.

Simulated output ripple, switching pulse and step response of new ripple controlled converter

群馬大学 GUNMA UNIVERSITY

Kobayashi Laboratory

Synchronized Ripple Controlled Converter (Freq. Domain)



★ Simulation Results

- Output voltage ripple：8 mVpp
- Clock frequency: 1.0 MHz
- Major period of control pulse: 3us or 6us
- Ripple frequencies of the control pulse: 500kHz, 250kHz, 125kHz
- Peak levels: 450mV, 900mV, 2500mV

Simulated spectrum of
control pulse without analog noise modulation

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Outline

- Introduction
- Ripple Controlled Converter and Spread Spectrum
- <u>Spread Spectrum with Analog Noise Generator</u>
- Ripple Converter with Analog Noise Modulation
- Conclusion

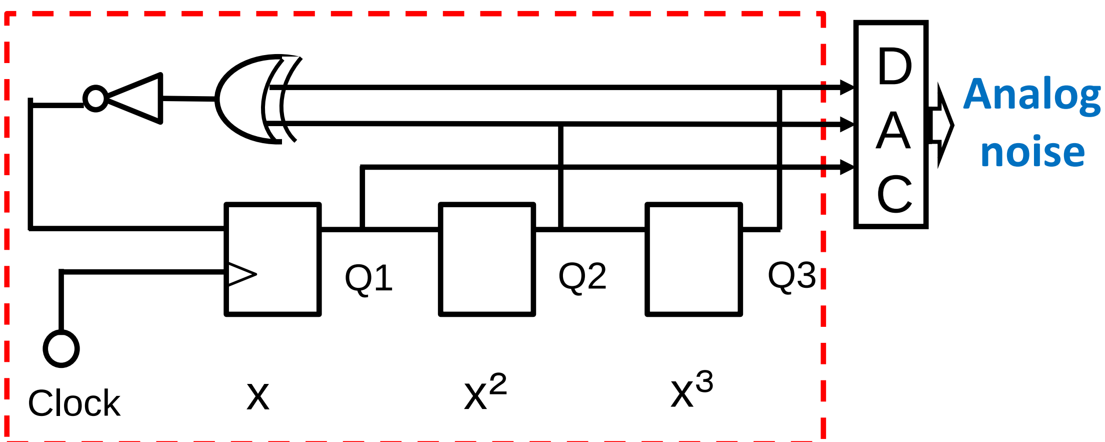
群馬大学
GUNMA UNIVERSITY

Kobayashi
Laboratory

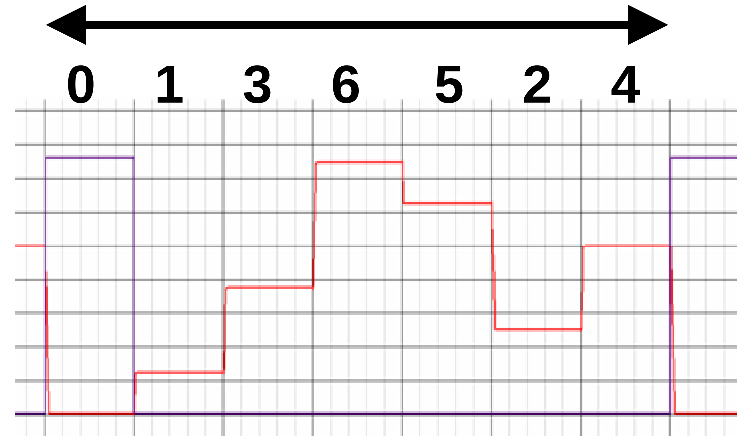
Analog Noise Generator

M-sequence circuit

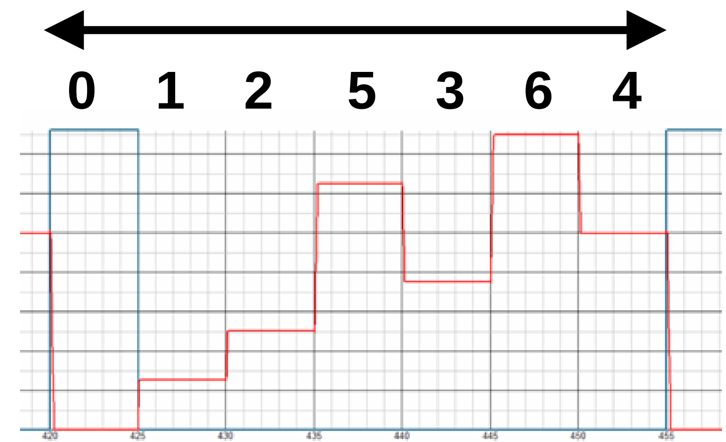
- Digital random noise generator
- Consists of an n-bit counter, EXOR gates
- Number of pulse levels : $N=2^n-1$
- Primitive polynomials (ex. 3 degrees)
  - (a) $G(s) = x^3+x^2+1$
  - (b) $G(s) = x^3+x+1$



M-sequence circuit (3 bit)



(a) x^3+x^2+1

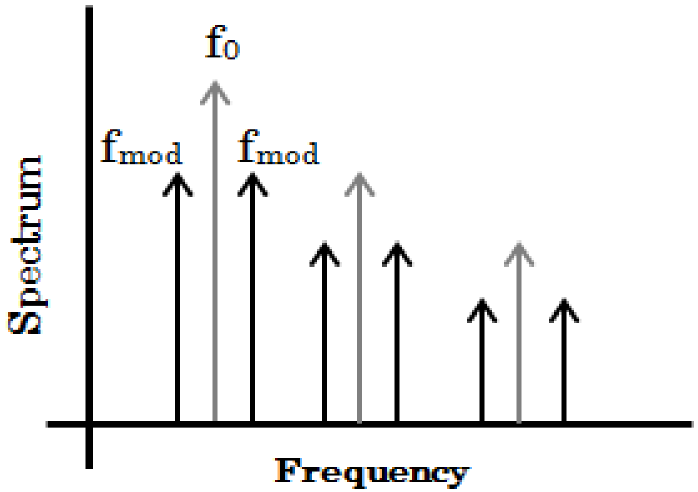


(b) x^3+x+1

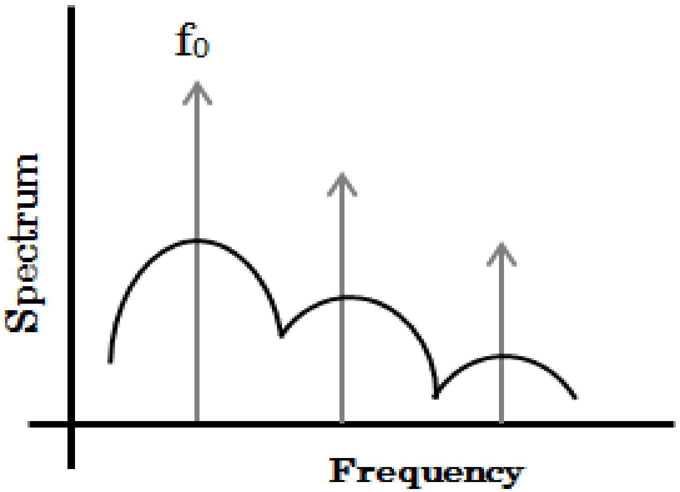
Output waveforms

Spread Spectrum with Analog Noise Generator

EMI reduction with digital and analog spread spectrum techniques



(a)Digital Spread



(b)Analog Spread

Noise spectrums are discrete.

Noise spectrums are continuous.

↓

More peak-reduction

群馬大学 GUNMA UNIVERSITY

Kobayashi Laboratory

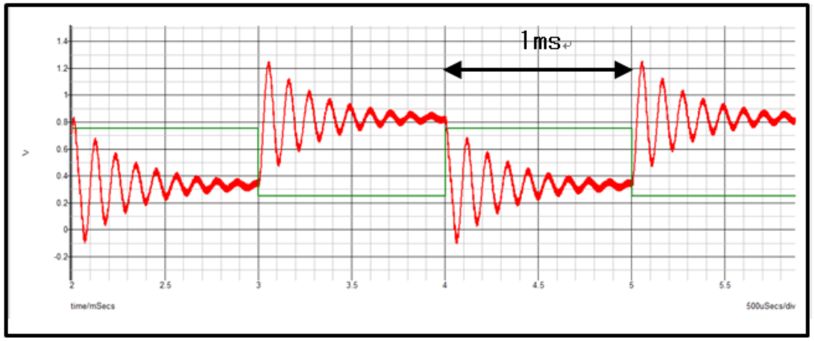
Analog Noise Generator Configuration

∗ M-sequence + DAC ⇒ Random Pattern Generator

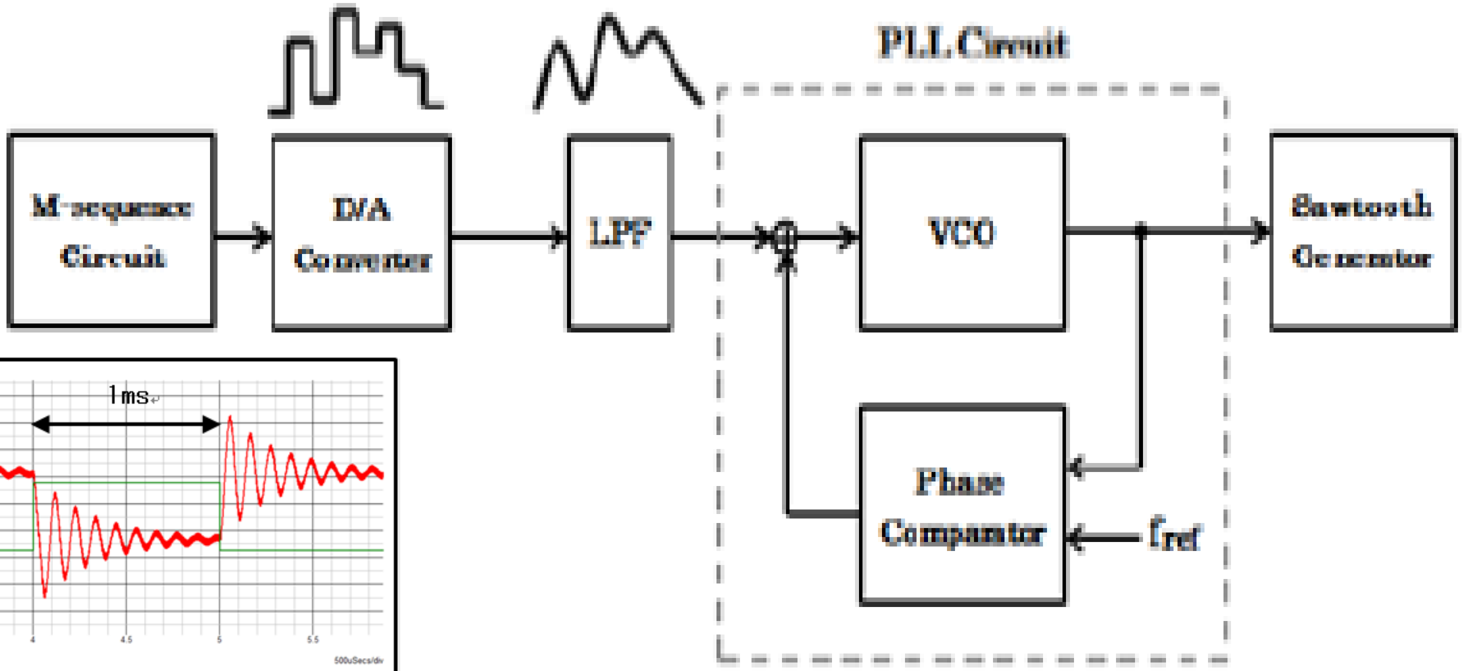
∗ +LPF ⇒ Analog Smooth Signal (Periodic)

∗ +PLL ⇒ Non-Periodic Frequency Modulated Pulses

∗ Step response of PLL circuit is unsteady.



Step response of PLL circuit

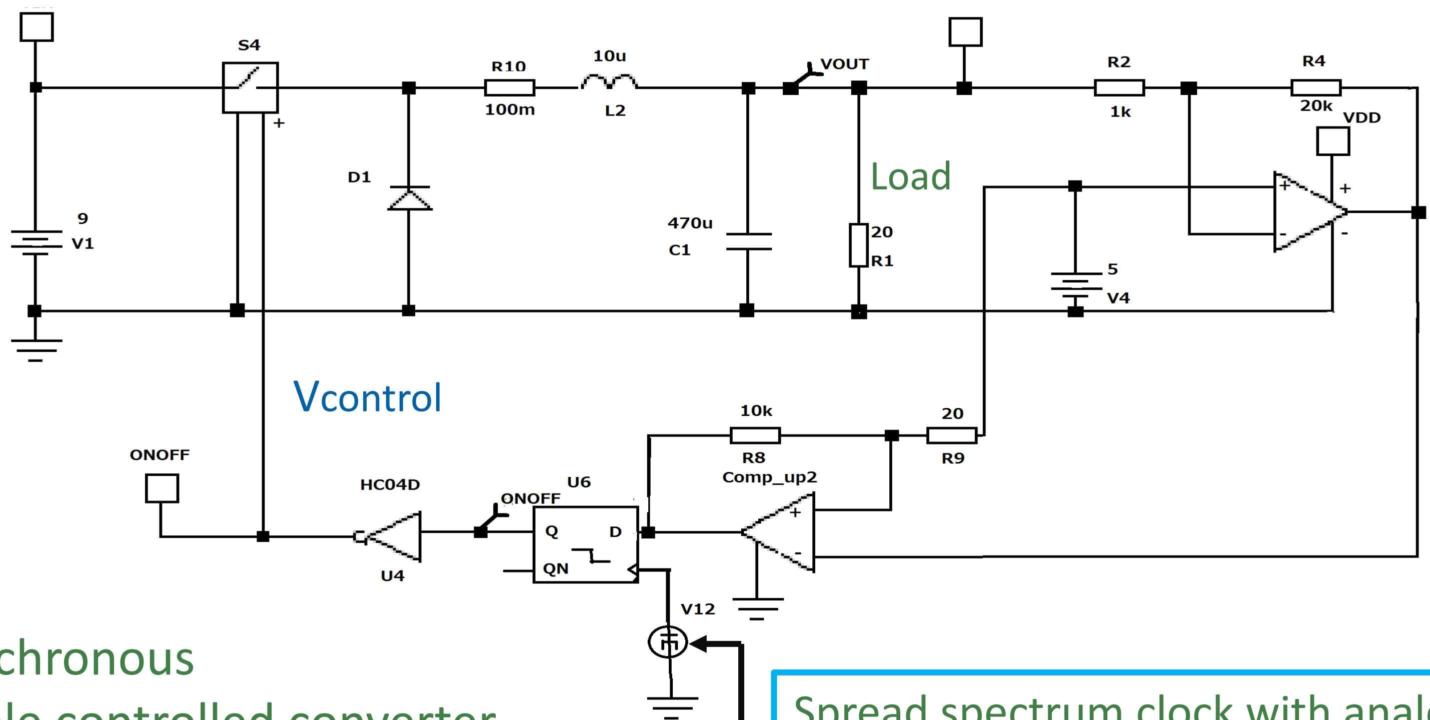


Analog noise with PLL circuit

Outline

- Introduction
- Ripple Controlled Converter and Spread Spectrum
- Spread Spectrum with Analog Noise Generator
- Ripple Converter with Analog Noise Modulation
- Conclusion

Proposed Ripple Controlled Converter with SSCG



Spread spectrum clock with analog noise
M-sequence circuit + DAC + LPF + PLL

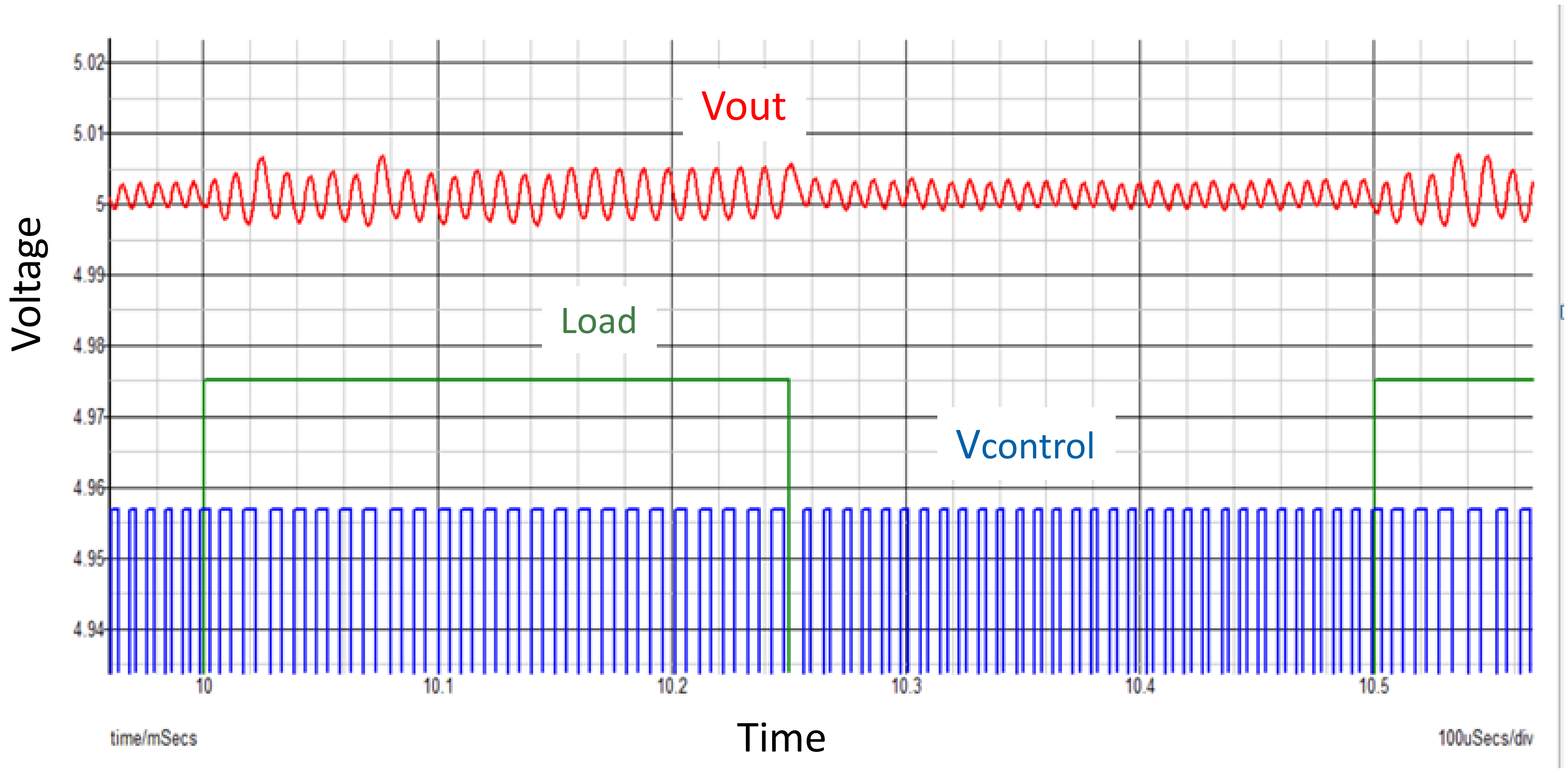
Synchronous
ripple controlled converter

群馬大学
GUNMA UNIVERSITY

SSCG: Spread Spectrum Clock Generator

Kobayashi Laboratory

Ripple Converter with Analog Noise Modulation (Time Domain)

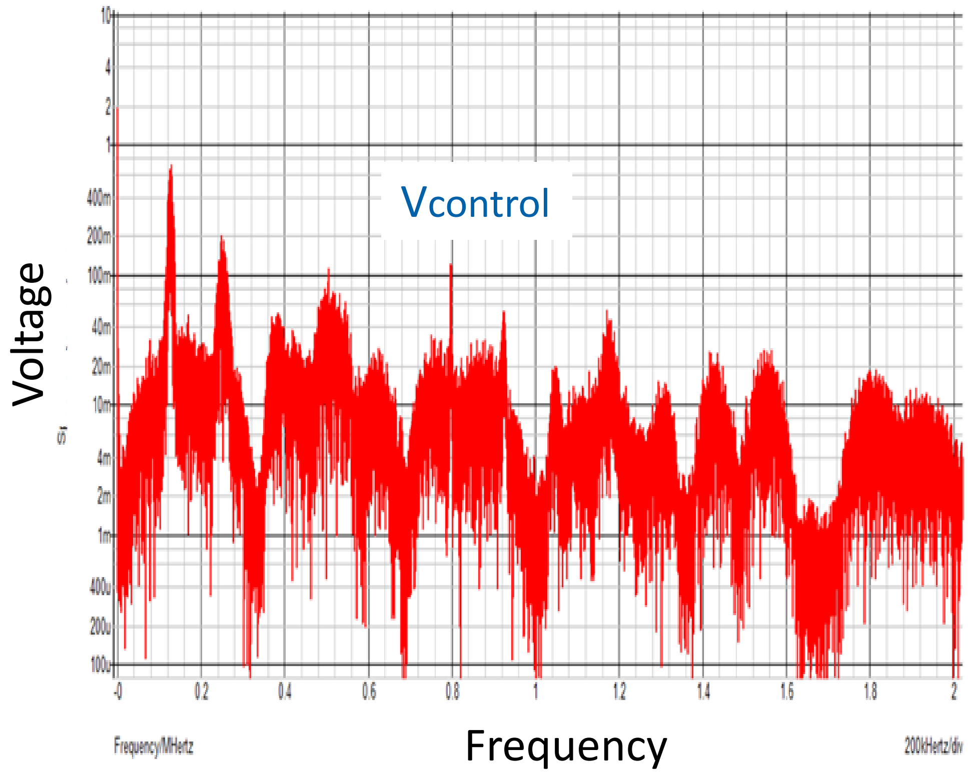


Simulated output ripple
with the proposed analog noise modulation

群馬大学
GUNMA UNIVERSITY

Kobayashi
Laboratory

Ripple Converter with Analog Noise Modulation (Feq. Domain)



★ Simulation Results

● The highest peak level of the spread spectrum: 700 mV at 125 kHz reduction by 1.8V (-5.5dB).

● At 250 kHz, the peak level is reduced by 700 mV (-6.5dB).

Simulated spread spectrum of
new ripple controlled converter with analog noise modulation

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Outline

- Introduction
- Ripple Controlled Converter and Spread Spectrum
- Spread Spectrum with Analog Noise Generator
- Ripple Converter with Analog Noise Modulation
- <u>Conclusion</u>

群馬大学
GUNMA UNIVERSITY

Kobayashi Laboratory

Conclusion

- Ripple Controlled Converter
  - Fast response
  - Small circuit

  ↓ Synchronization

  Stable Operation

  ↓ Spread spectrum clock with analog noise
  M-sequence circuit + DAC + LPF + PLL

  EMI Reduction

- Effectiveness is confirmed with simulation

Thank you for listening

謝謝