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Continuous-Time Feed-Forward Delta-Sigma Controller for DC-DC Converter

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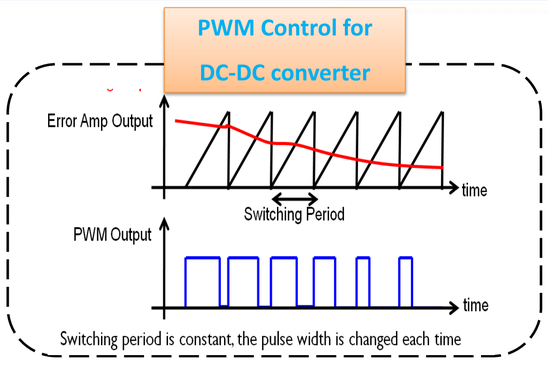
Introduction



Switching period is constant,
the pulse width is changed each time

Difficult to meet simultaneously both of
- Fast Transient Response
- High Efficiency

On The Other Hand

DC-DC converters are everywhere

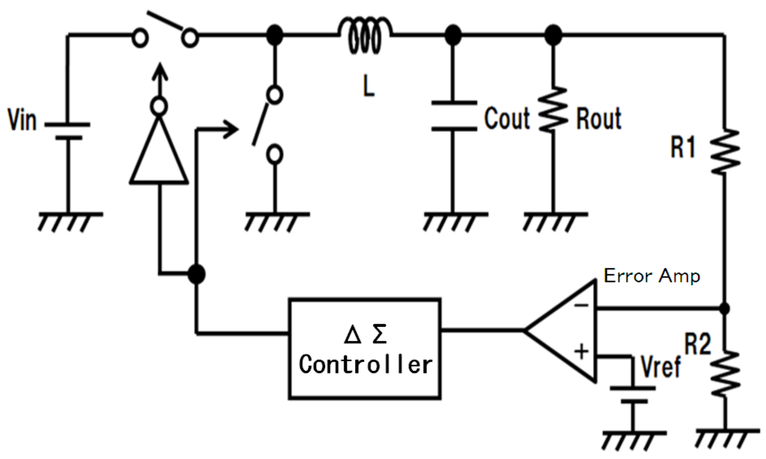
Power device advances

Fast switching speed

ΔΣ modulator for DC-DC converter

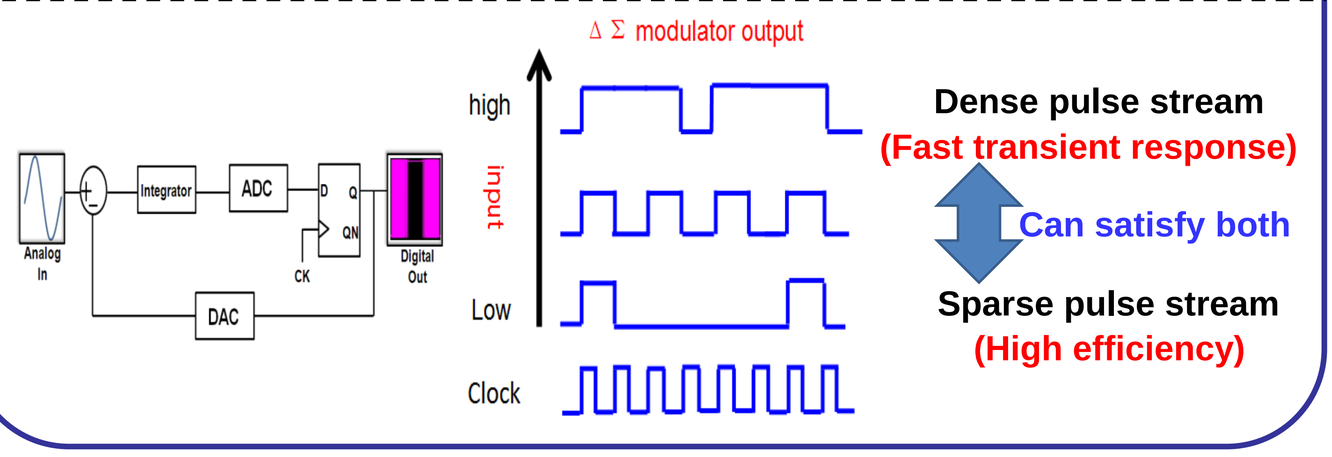
Expected advantages:
-Fast Transient Response
-High Efficiency at Low Load
-Spread Spectrum of Switching noise

ΔΣ DC-DC Converter



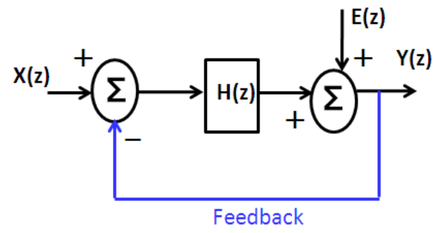
parameters

Vin	12V
Vref	5V
L	22uH
Cout	220uF
Rout	10Ω
Fck	2MHz



Delta-Sigma Modulators

FB ΔΣ Modulator



$$Y(z)=\frac{H(z)}{1+H(z)}\cdot X(z)+\frac{1}{1+H(z)}\cdot E(z)$$

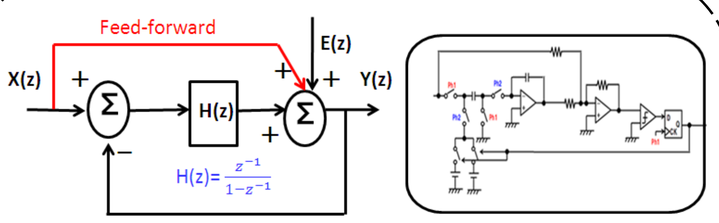
$H(z)=\frac{z^{-1}}{1-z^{-1}}$ → STF(z)= z^{-1} NTF(z)= $1-z^{-1}$

One-clock delay

Differentiation=Noise Shaping

1st-order Feedback ΔΣ

FF ΔΣ Modulator



$$Y(z)=1\cdot X(z)+\frac{1}{1+H(z)}\cdot E(z)$$

STF(z)= 1 NTF(z)= $1-z^{-1}$

signal transfer function

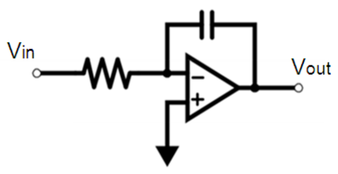
noise transfer function

No Delay

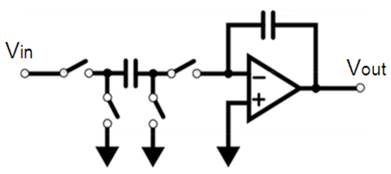
Differentiation=Noise Shaping

1st-order Feed-forward ΔΣ

CT ΔΣ modulator
- Low power
- High-speed, high-frequency
- Time constant (RC) variation

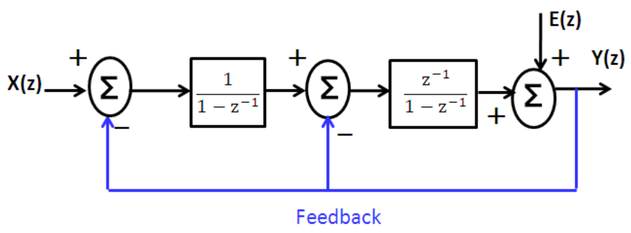


DT ΔΣ modulator
- High precision
- High power consumption
- low-speed, low-frequency



CT ΔΣ modulator

Application to DC-DC converter controller

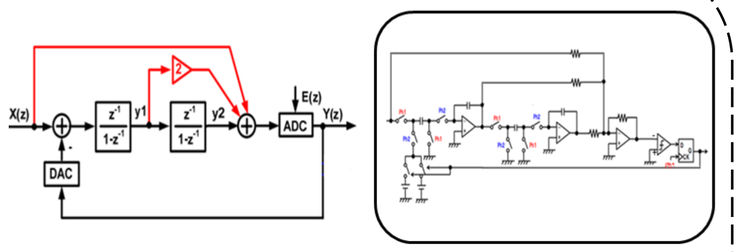


$$Y(z)=z^{-1}\cdot X(z)+(1-z^{-1})^2\cdot E(z)$$

One-clock delay

2nd-order Differentiation

2nd-order Feedback ΔΣ



$$Y(z)=1\cdot X(z)+(1-z^{-1})^2\cdot E(z)$$

STF= 1 NTF= $(1-z^{-1})^2$

No Delay

2nd-order Differentiation

2nd-order Feed-forward ΔΣ

	No Delay	High Frequency	Small Ripple	Low Power	High Precision
1st CT FF ΔΣ	◎	◎		◎	
1st DT FF ΔΣ	◎				◎
1st CT FB ΔΣ		◎		◎	
1st DT FBΔΣ					◎
2nd CT FF ΔΣ	◎	◎	◎	◎	
2nd DT FF ΔΣ	◎		◎		◎
2nd CT FB ΔΣ		◎	◎	◎	
2nd DT FB ΔΣ			◎		◎

Comparison of all kinds ΔΣ modulator

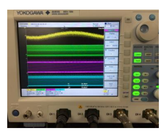
Conclusion

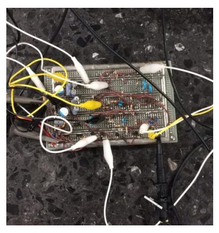
Continuous-Time, Feed-forward ΔΣ modulator has
- The fastest transient response
- With comparable voltage ripple

Low power implementation is expected.

Future Work: Investigation of R,C variation effect

Experimental verification is underway





References

1) H. Gao, L. Xing, Y. Kobori, F. Zhao, H. Kobayashi, S. Miwa, A. Motozawa, Z. Nosker, K. Niitsu, N. Takai, T. Odaguchi, I. Nakanishi, K. Nemoto, J. Matsuda, "DC-DC Converter with Continuous-Time Feed-Forward Sigma-Delta Modulator Control", IEEE Asia Pacific Conference on Circuits and Systems, Kaohsiung, Taiwan (Dec. 2012).

2) Y. Kobori, M. Kono, T. Shimizu. H. Kobayashi, "Noninverted Buck- Boost Converters with Dual Sigma-Delta Modulators", Electrical Engineering in Japan, Vol. 178, no.2, pp.21-28 (Jan. 2012).