ΔΣ Digital-to-Time Converter and its Application to SSCG*

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*SSCG : Spread Spectrum Clock Generator

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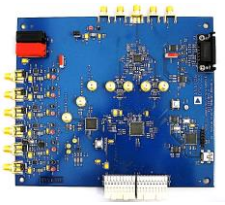
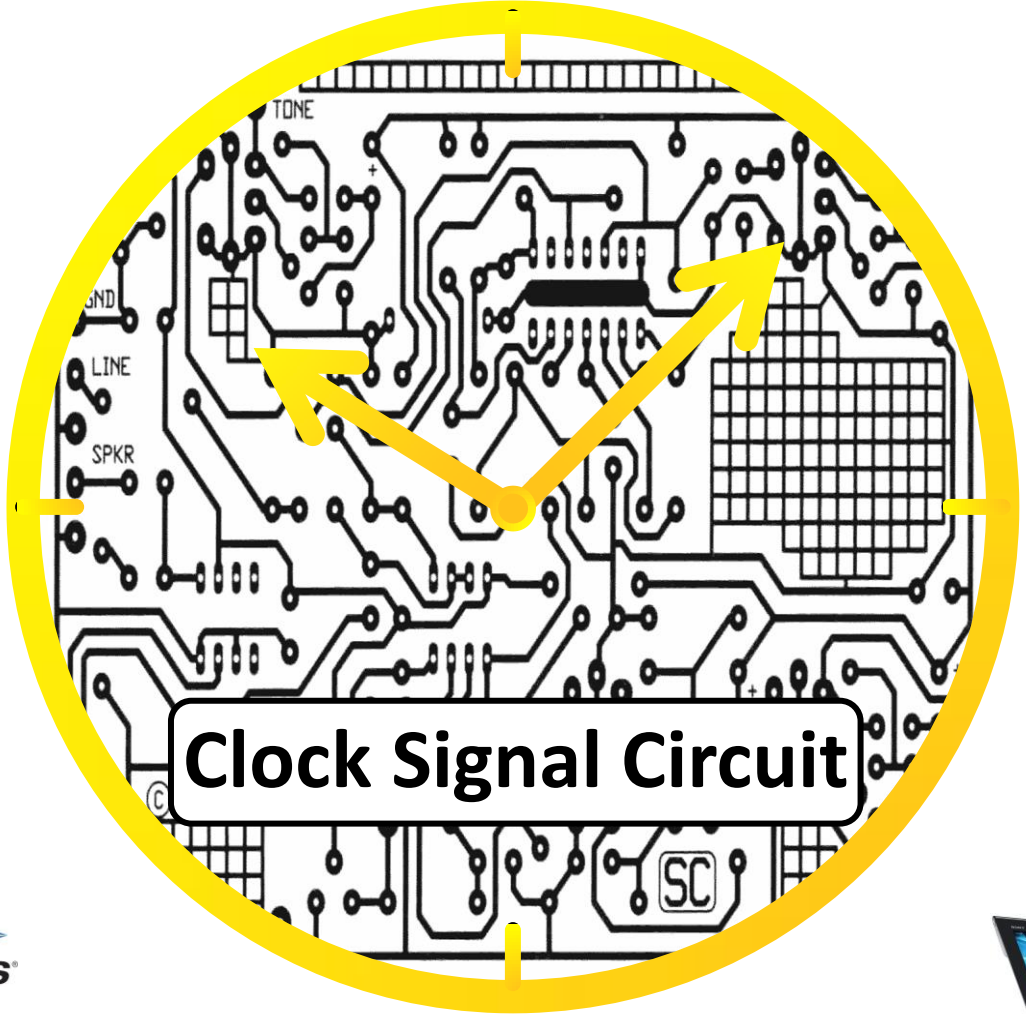
Outline

I. Background
II. Principle
    i. PCMΔΣDTC Algorithm
    ii. PPMΔΣDTC Algorithm
    iii. PWMΔΣDTC Algorithm
    iv. PRJΔΣDTC Algorithm
    v. Other Possible Algorithms
III. Analysis
IV. Result
V. Conclusion

Outline

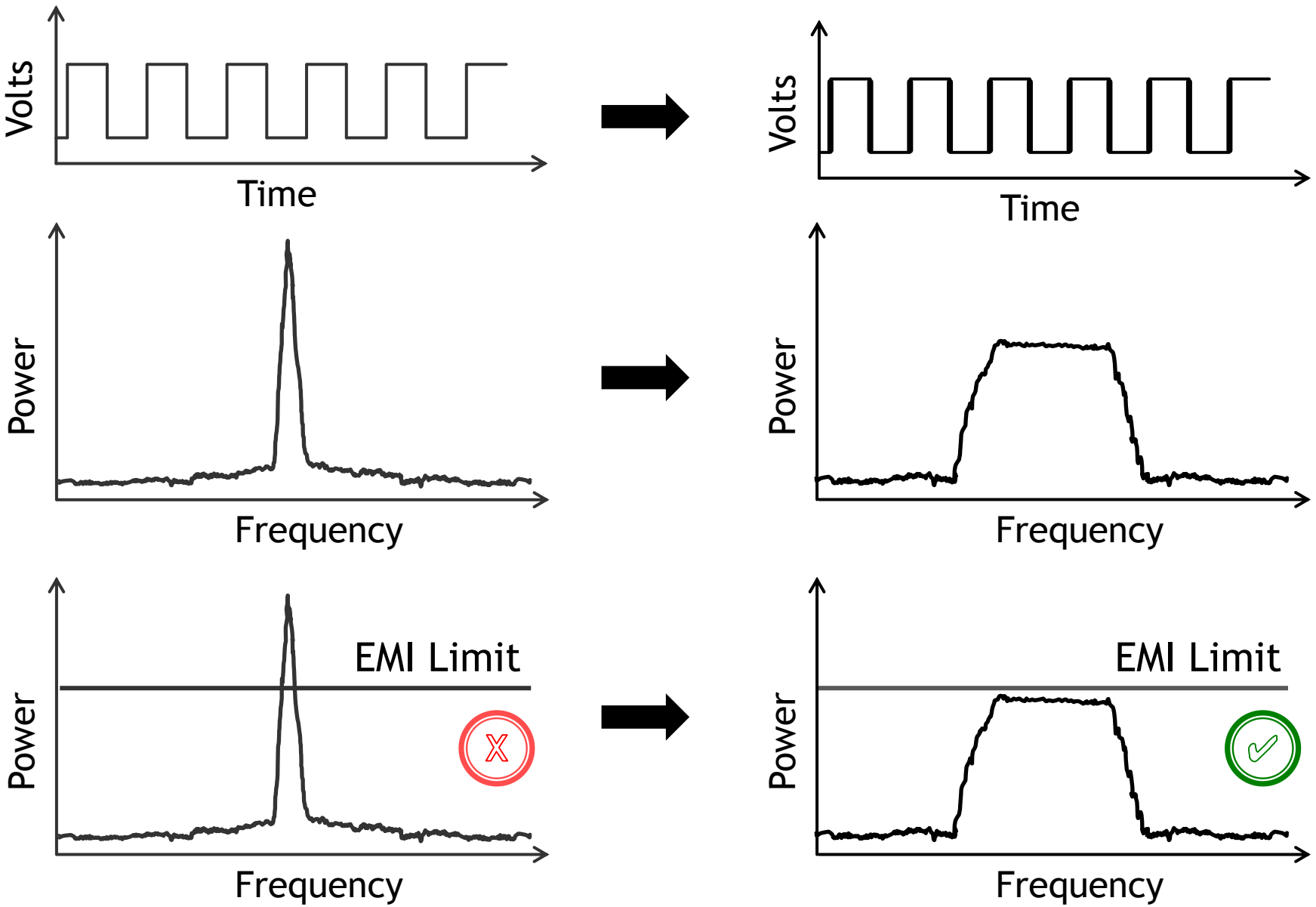
Common Object in All Electronic Devices



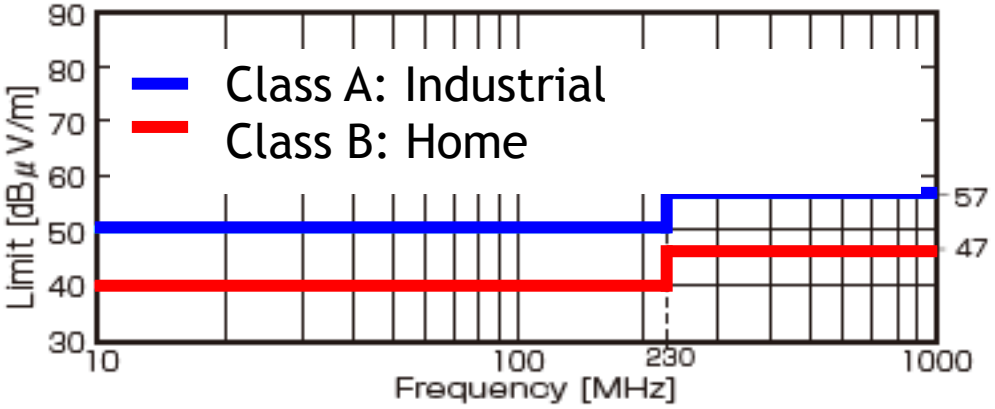


Clock is everywhere

Spread Spectrum Clock Technique

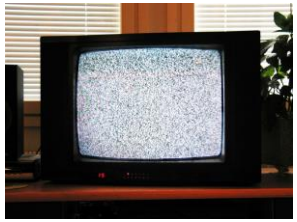


EMI Problem



EMI Regulation (CISPR22) in Japan

Ignoring is Dangerous



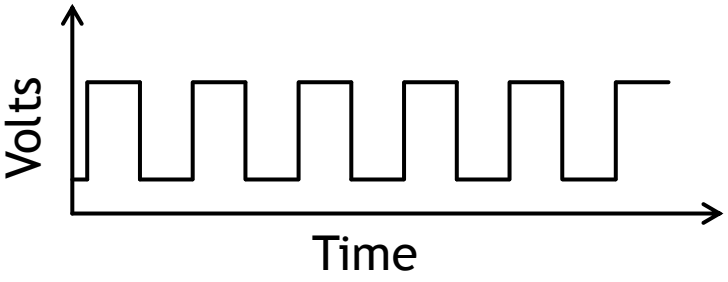
Lead to Malfunctioning of devices

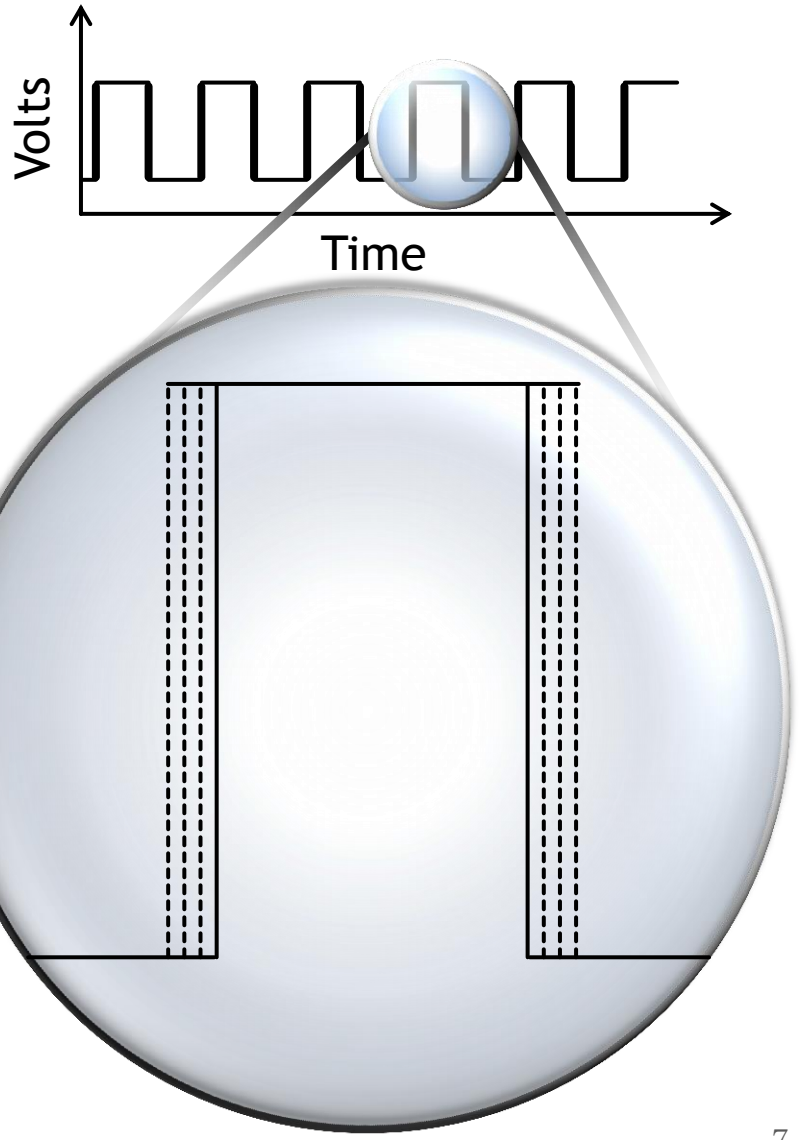
Solving is difficult

Time Consuming

Costly

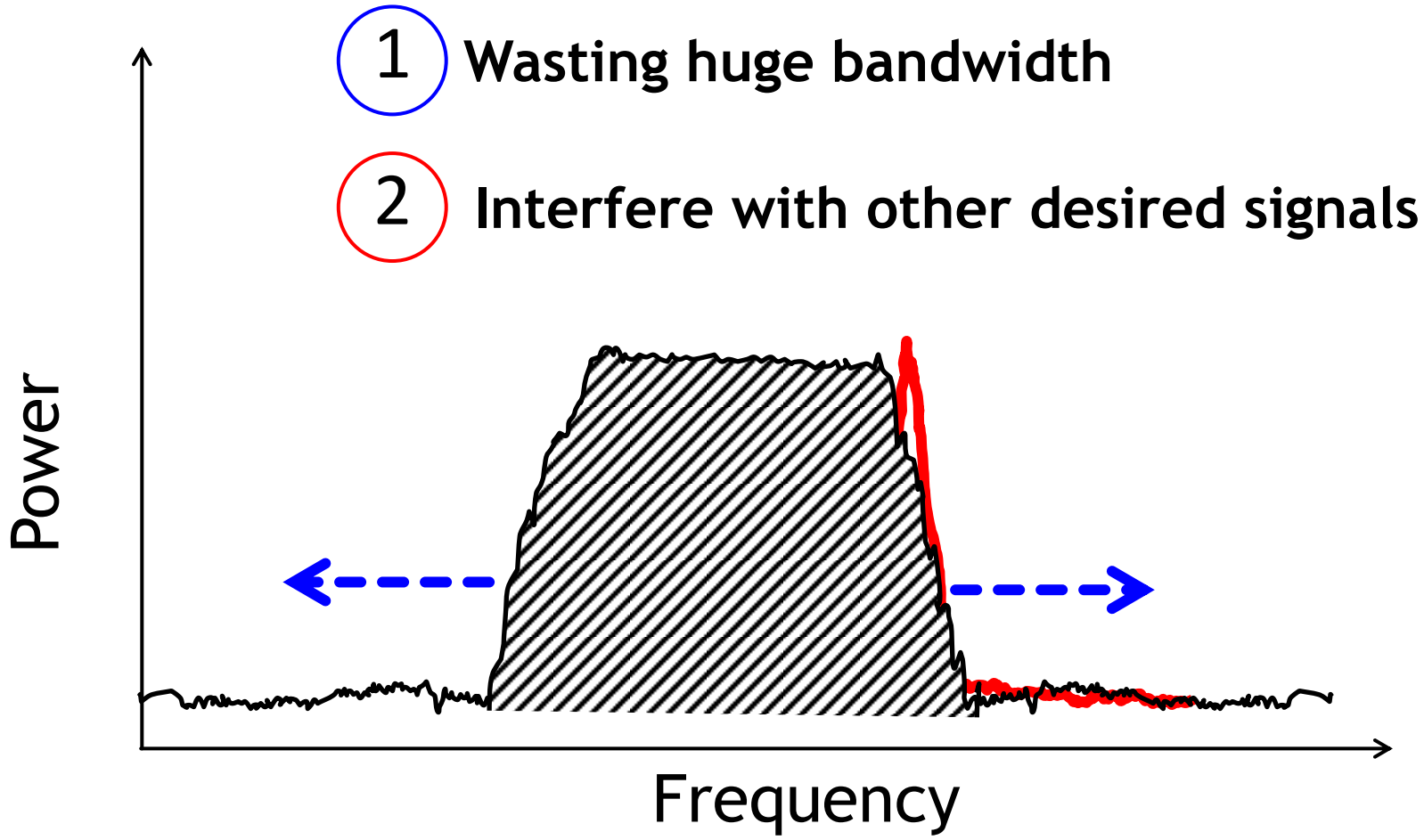
SSGC Approach





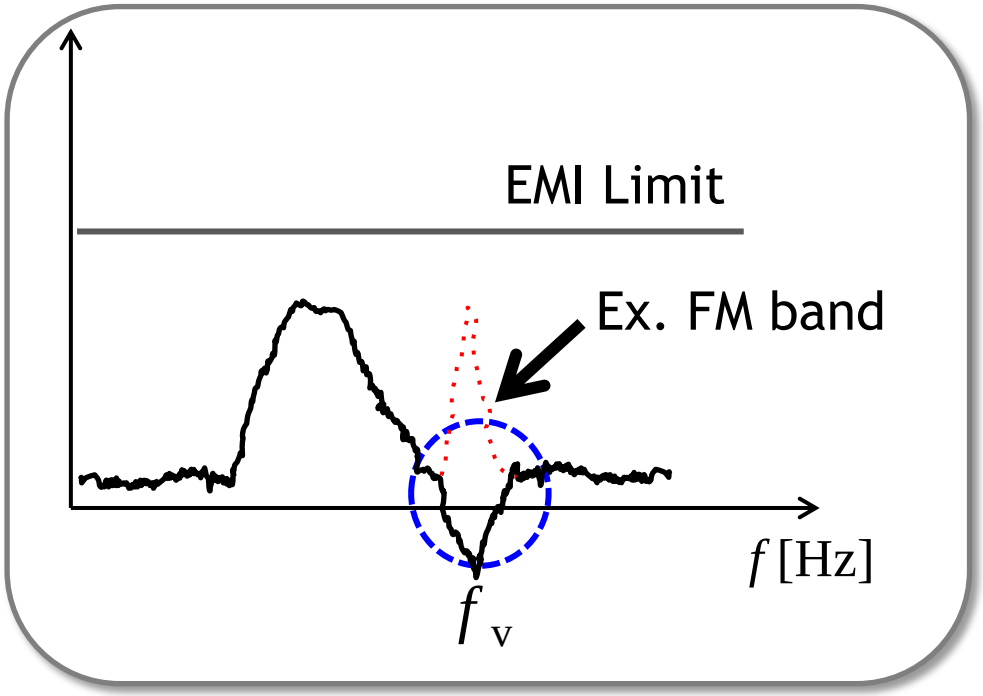
Solving Digital Problem By Analog Approach

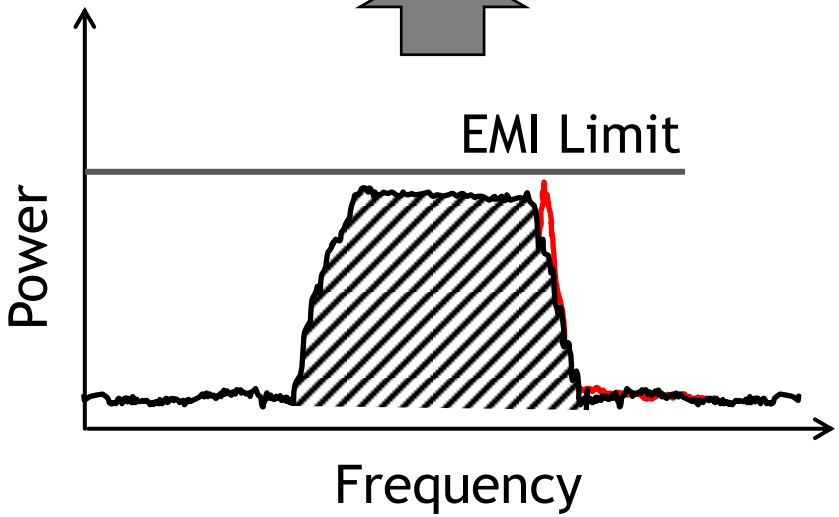
Conventional SSGC Problems



Exclusive Noise Spectrum Selection

Our Target:





Goal

To compete with conventional methods,
Our method should be:

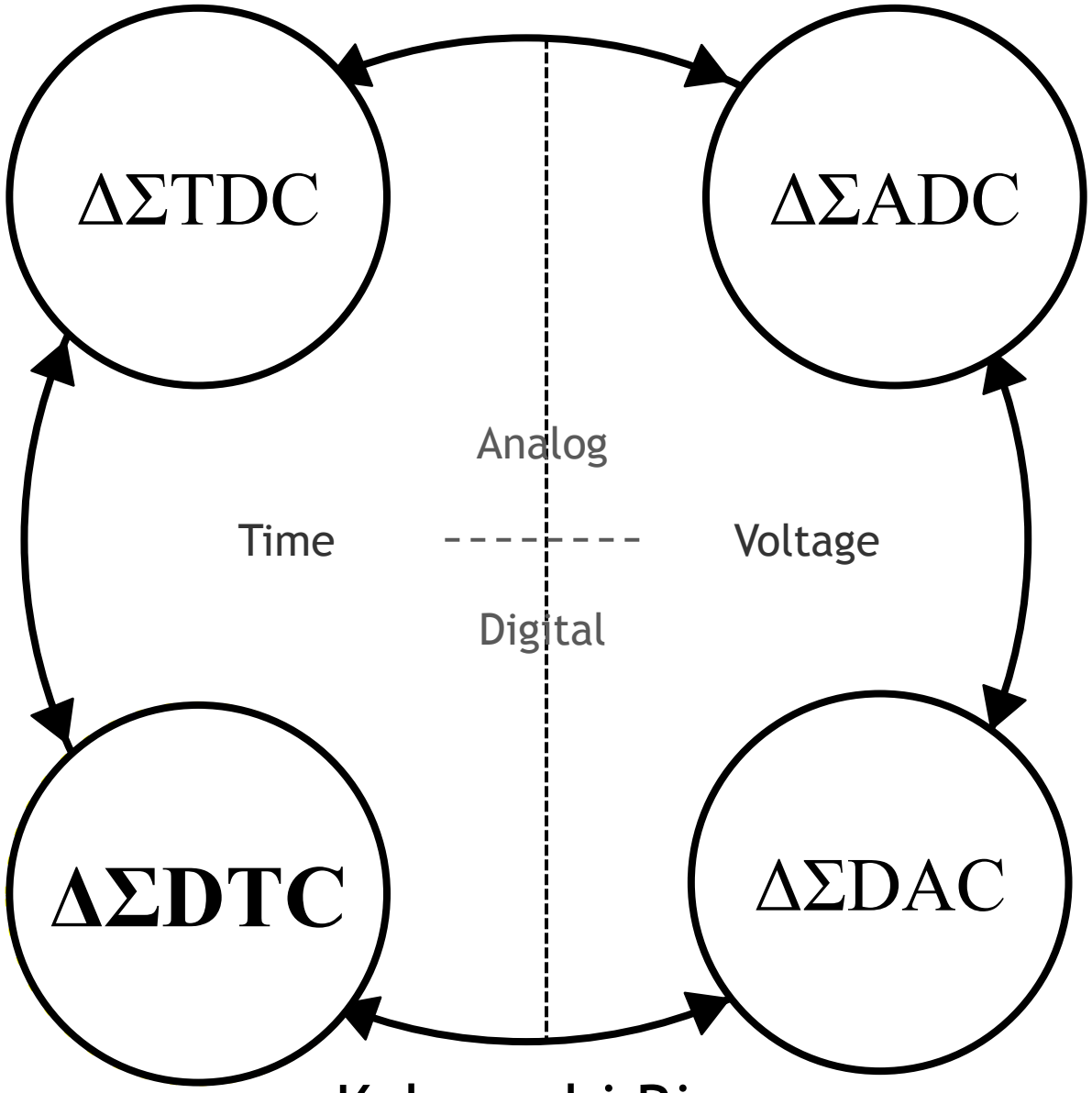
- ✓ **Simple**
- ✓ **Low cost**
- ✓ **Effective**

Converters Path

Devices miniaturization, speed, high frequency

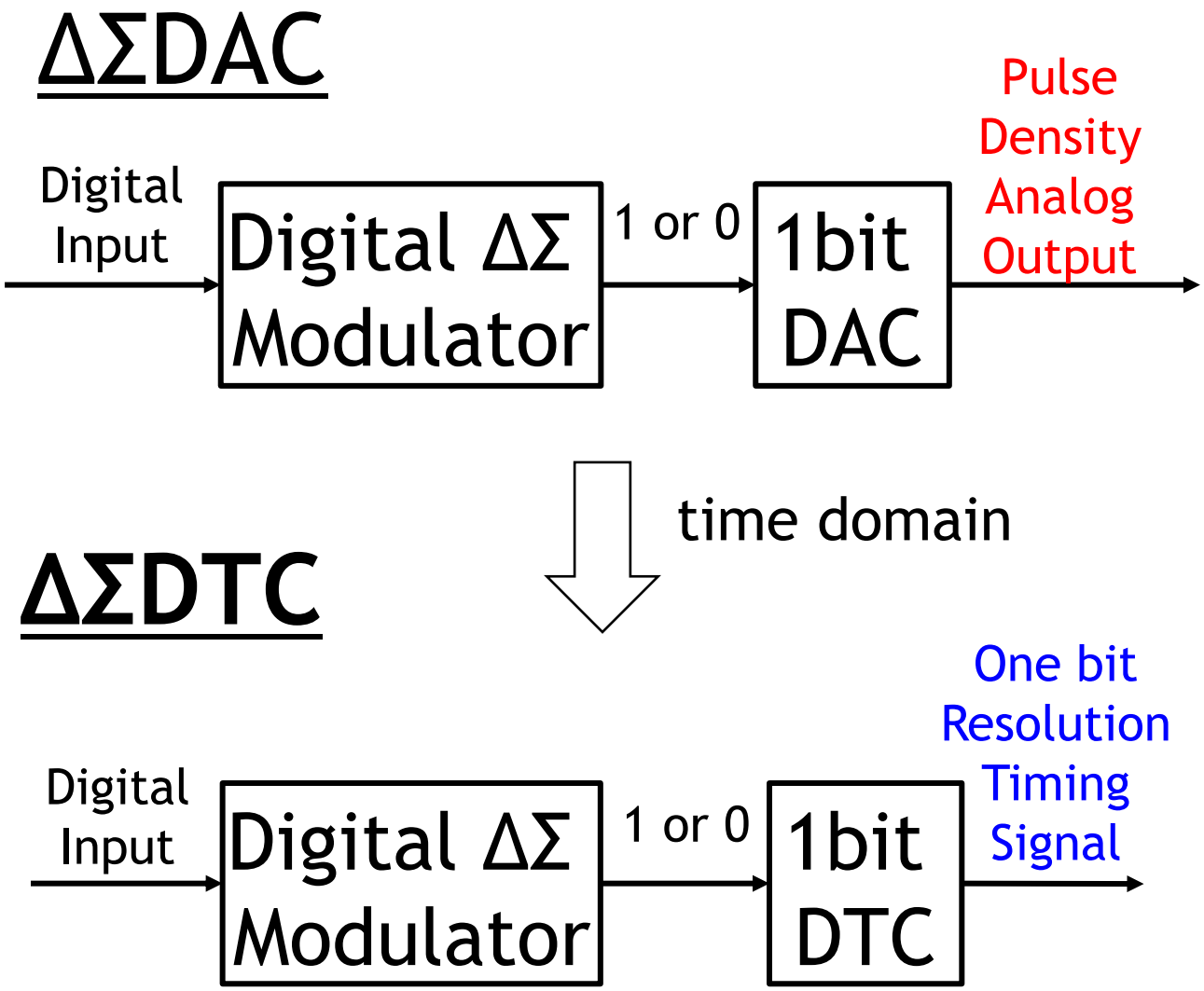
- Spreading ΔΣ oversampling Applications
  - **Time domain signal processing**
    - From ΔΣADC to ΔΣTDC
    - From ΔΣDAC to ???

Time Domain v.s. Voltage Domain



Kobayashi Ring

ΔΣDAC & ΔΣ DTC Analogy



Outline

I. Background
II. **Principle**
    I. **PCMΔΣDTC Algorithm**
    ii. PPMΔΣDTC Algorithm
    iii. PWMΔΣDTC Algorithm
    iv. PRJΔΣDTC Algorithm
    v. Other Possible Algorithms
III. Analysis
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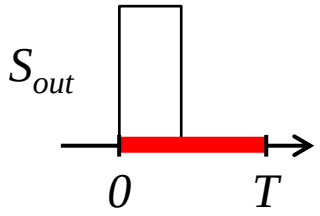
V. Conclusion

Pulse Cycle Modulation

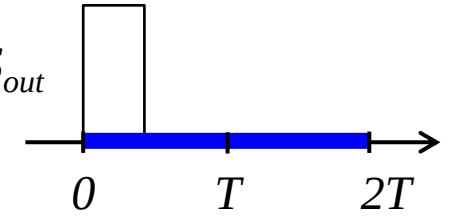
- Output Pulse Cycle Period = $f(D_{out})$

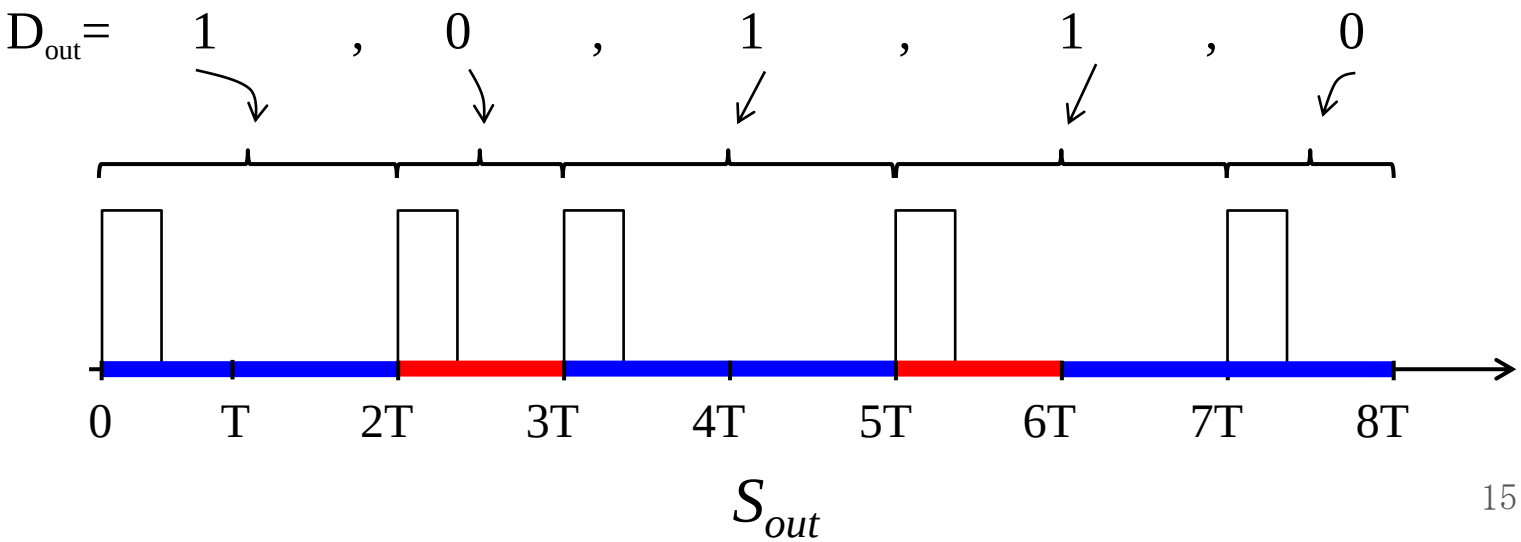
Exa. : (D_{out}=*10110*)

$D_{out} = 0$

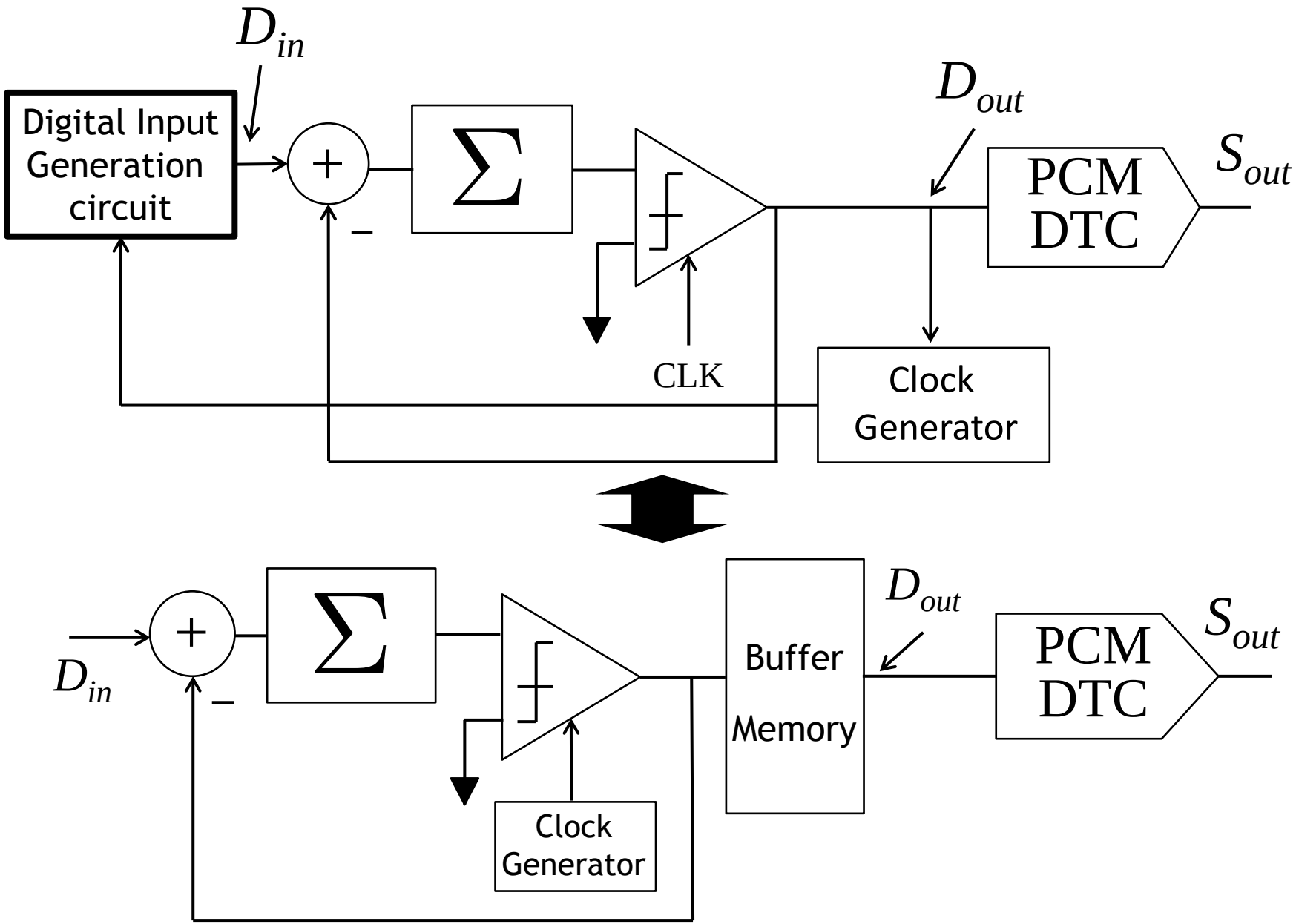


$D_{out} = 1$





PCMΔΣDTC – Configuration



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IV. Result
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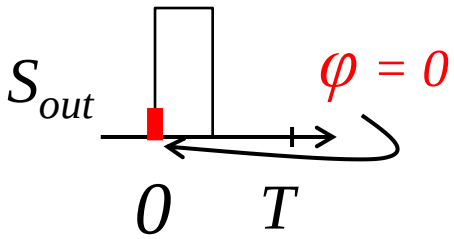
Pulse Position Modulation

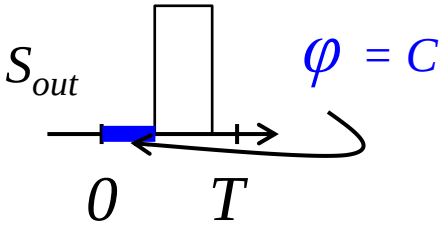
- Output pulse position (or phase) = $g(D_{out})$

Ex. (D=10110)

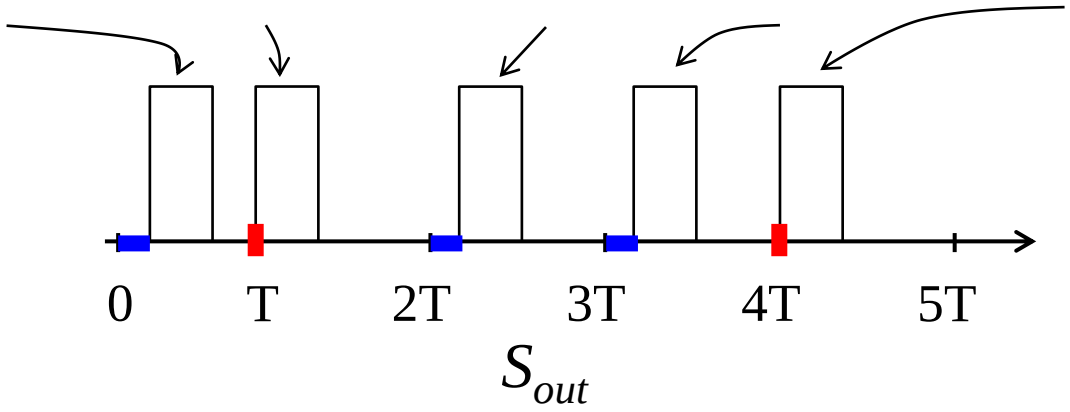
$D_{out} = 0$



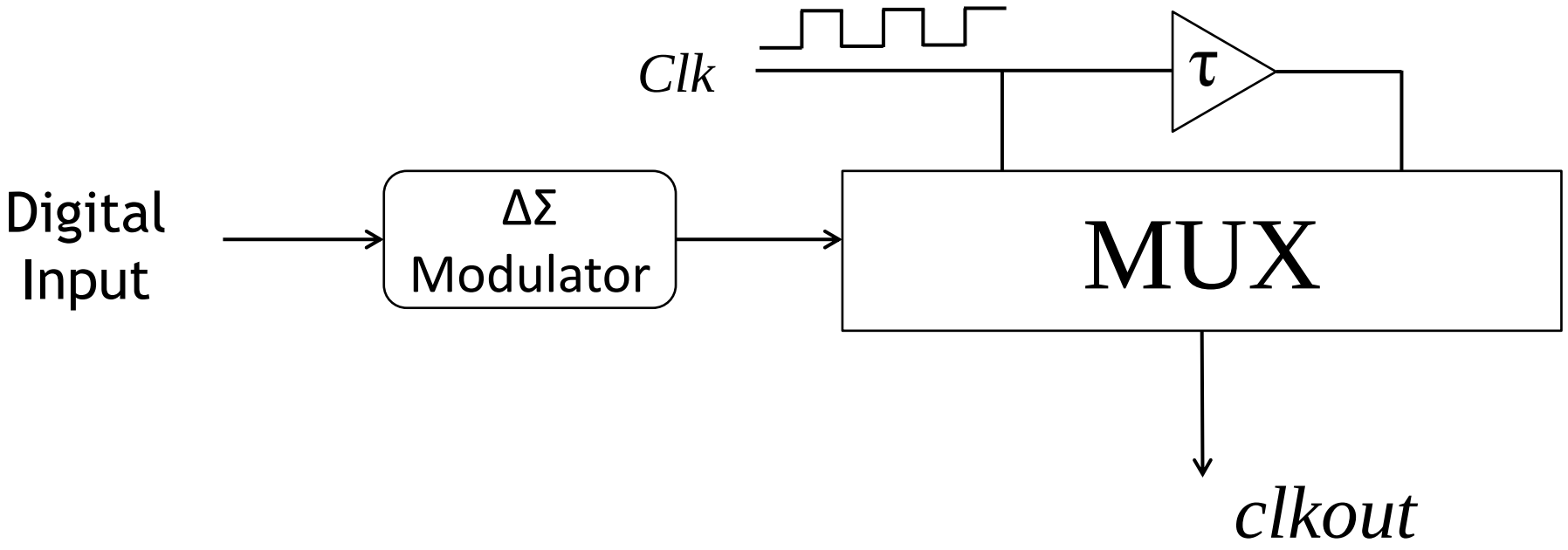
$D_{out} = 1$



D_{out} = 1 , 0 , 1 , 1 , 0



PPMΔΣDTC - Configuration



High Frequency Clock

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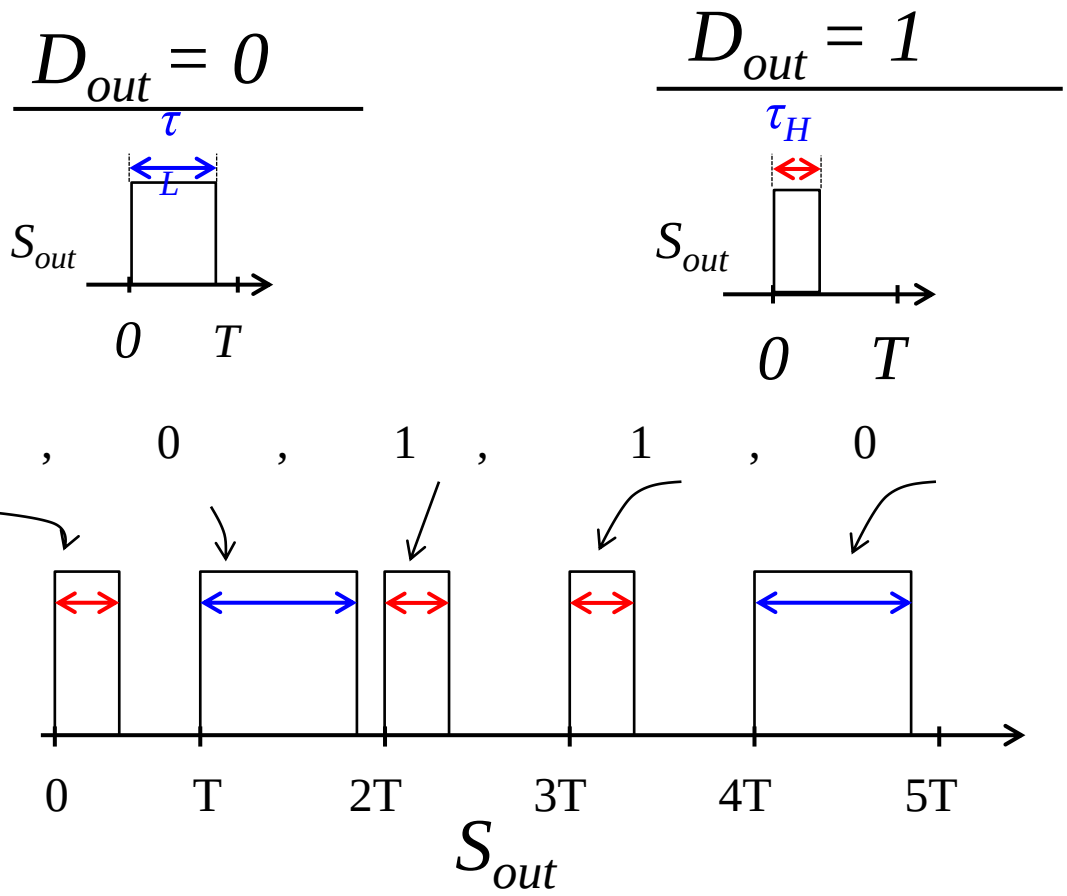
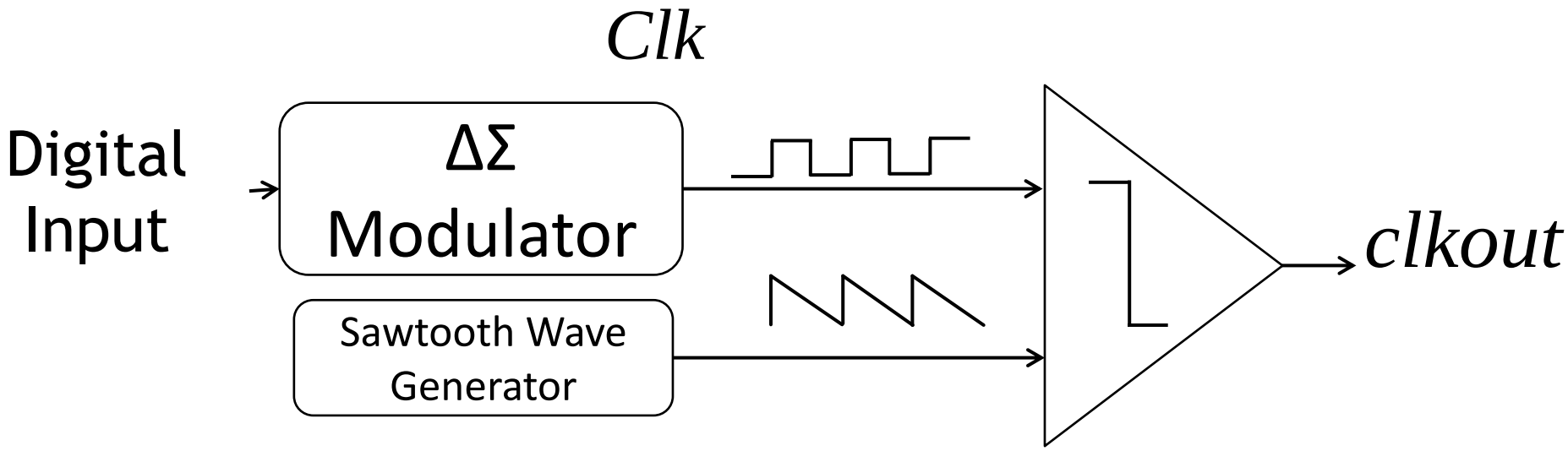
Pulse Width Modulation

- Output pulse width = $h(D_{out})$

Exa. : (D_{out}=*10110*)



PWMΔΣDTC - Configuration



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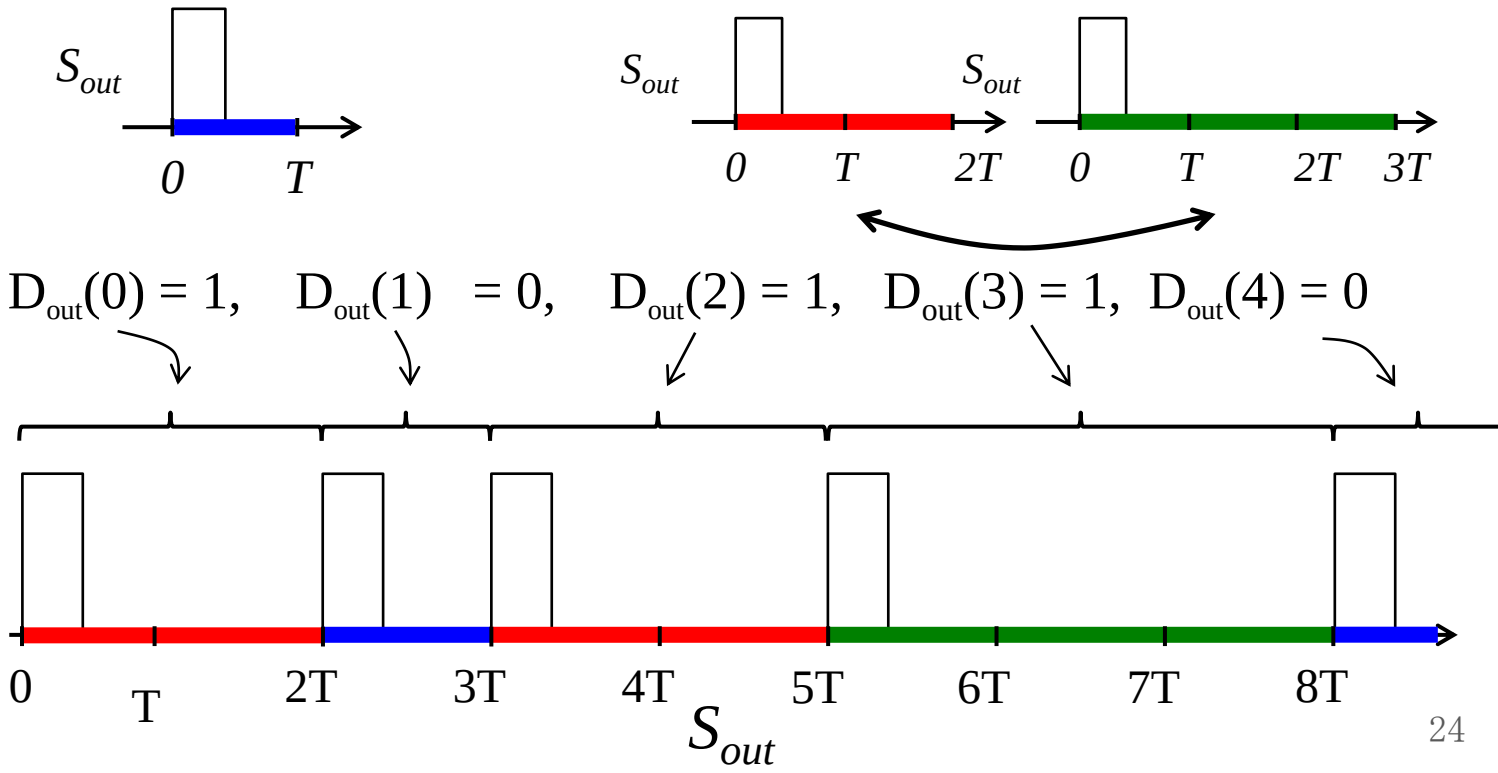
Pseudo Random Jitter

- Output pulse cycle = $k(D_{out},h)$

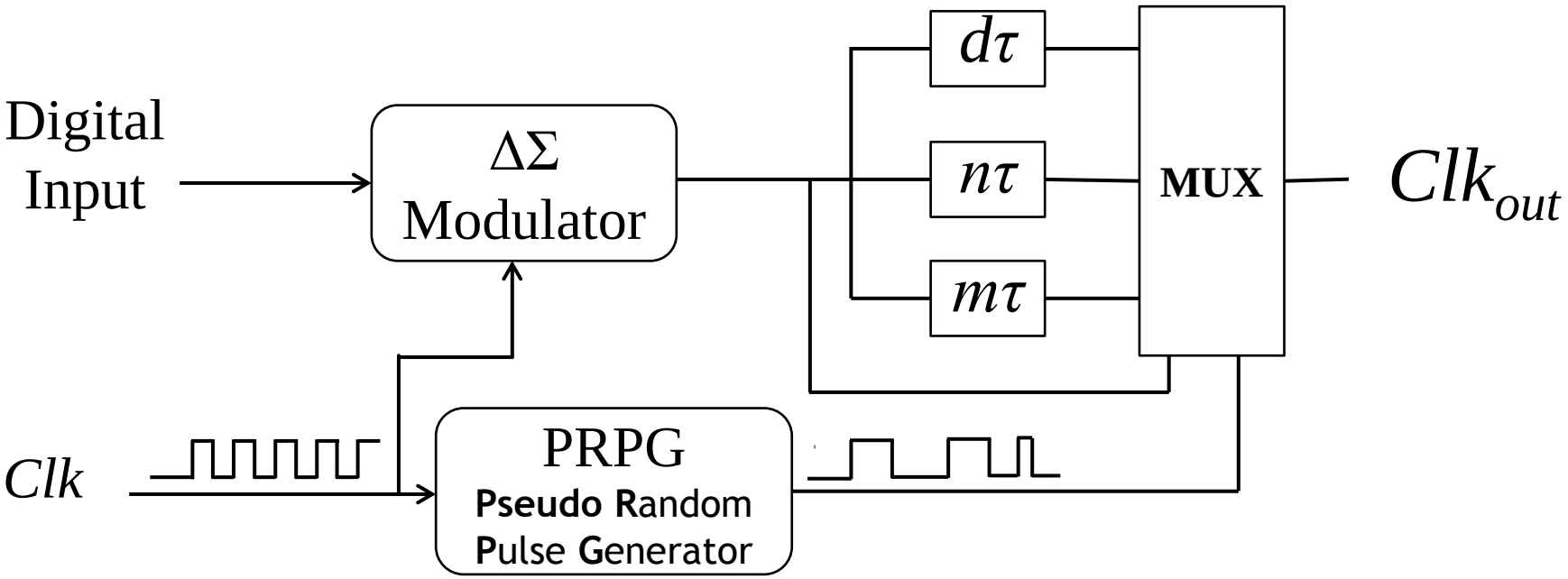
Exa. : (D_{out}=*10110*)

$D_{out} = 0$

$D_{out} = 1$



PRJΔΣDTC - Configuration



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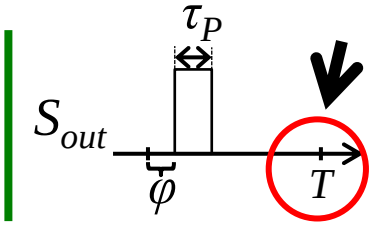
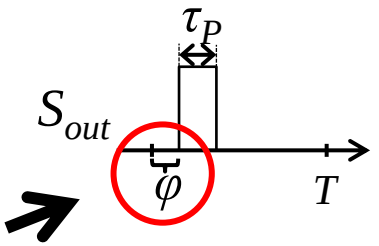
Compound DTC…

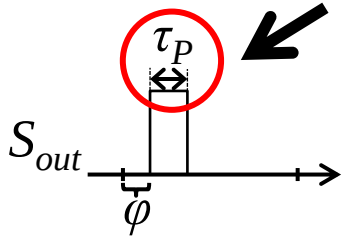
PCMDTC: *based on digital Input Alter T*



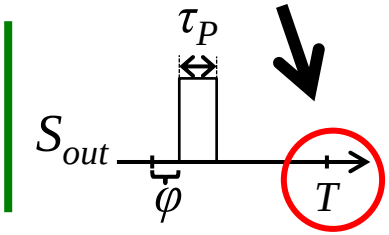
PPMDTC: *Alter φ*



PWMDTC: *Alter τ_P*



PRJDTC: *Alter T randomly*



PPCMDTC, PPWMDTC,PPCRJCDTC, …

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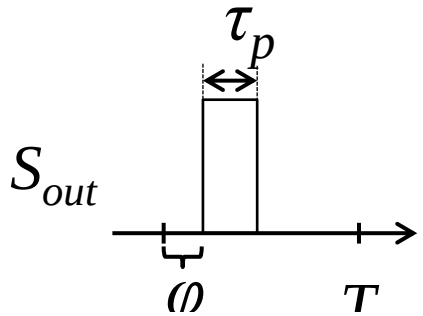
SSGC with Exclusive Noise Spectrum using ΔΣDTC

Digital Pulse

T_C = 1 (base) , $T = nT_C$, $\tau_P = mT_C$, $\varphi = 2\pi q/n$



PCMΔΣDTC

$$f_{notch} = \frac{K \times (n_H + n_L)}{2|n_H - n_L|} f_s \quad (1)$$

$$K = |n_H - n_L| - 1, |n_H - n_L| - 2, \cdots, 1.$$

n_H , n_L = 1, 2, 3, 4,...,

defined as $n_H = T_H/T_C$, $n_L = T_L/T_C$.

PPMΔΣDTC

$$f_{notch} = \frac{K}{|q_H - q_L|} f_s \quad (2)$$

$$K = |q_H - q_L| - 1, |q_H - q_L| - 2, \cdots, 1.$$

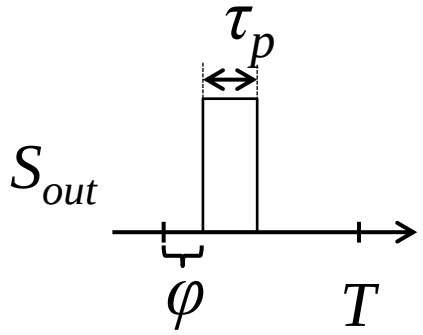
q_H , q_H = 1, 2, 3, 4,...,

defined as $q_H = n_H(\phi_H/2\pi)$, $q_L = n_L(\phi_L/2\pi)$.

SSGC using Delta-Sigma DTC

Digital Pulse

T_C = 1 (base) , $T = nT_C$, $\tau_P = mT_C$, $\varphi = 2\pi q/n$



PWMΔΣDTC

$$f_{notch} = \frac{K}{|m_H - m_L|} f_s \tag{3}$$

$$K = |m_H - m_L| - 1, |m_H - m_L| - 2, \cdots, 1.$$

m_H , m_L = 1, 2, 3, 4,...,

defined as $m_H = \frac{\tau_H}{T_C}$, $m_L = \frac{\tau_L}{T_C}$.

PRJΔΣDTC

$$f_{notch} \simeq K(\frac{4n_L + p + q}{4G}) f_s \tag{4}$$

$$K = G - 1, G - 2, \cdots, 1.$$

G is the greatest common divisor between p and q

$$p = |n_{H1} - n_L|, q = |n_{H2} - n_L|.$$

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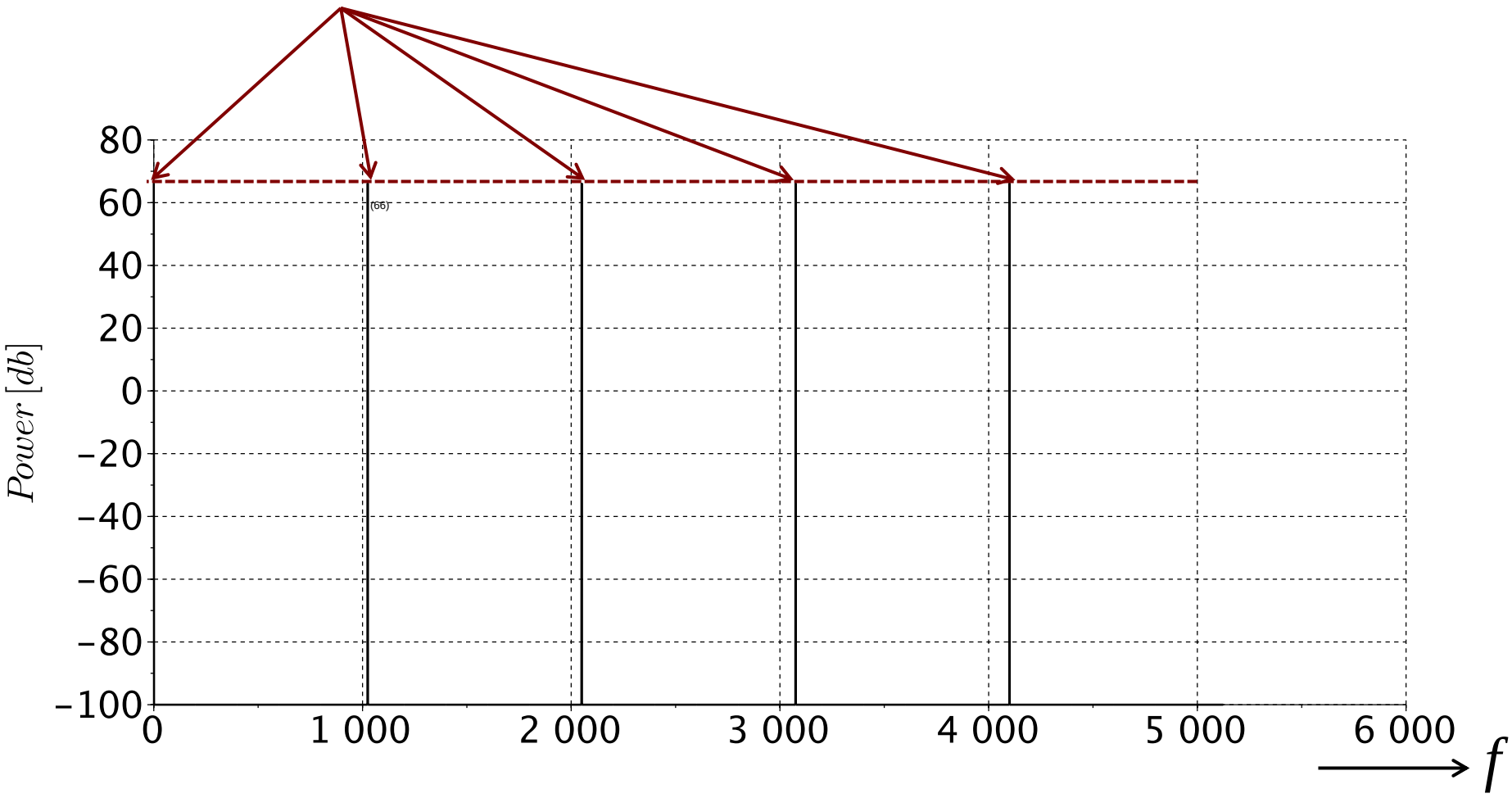
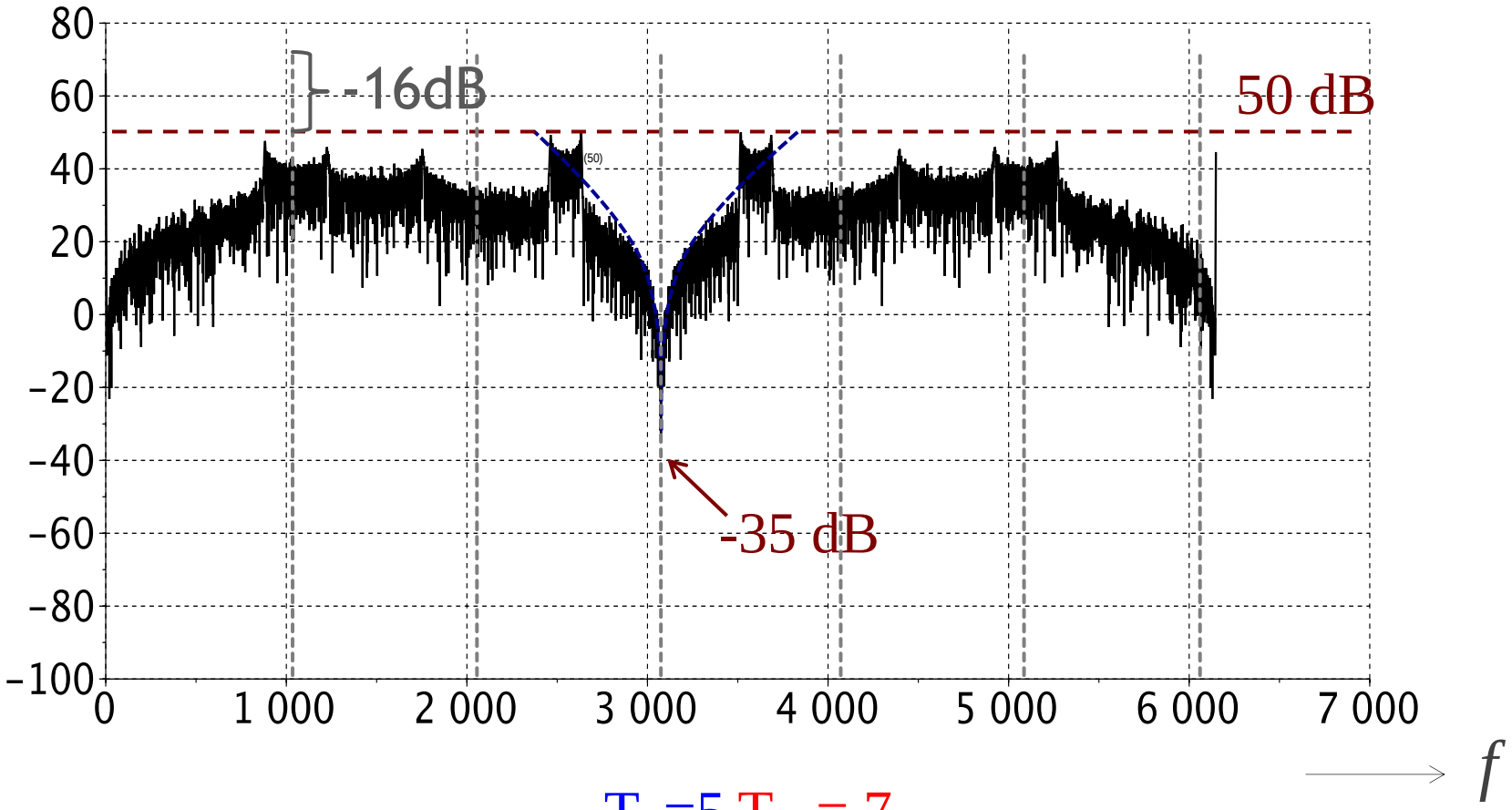
Result · Clock's PSD （Without DTC）

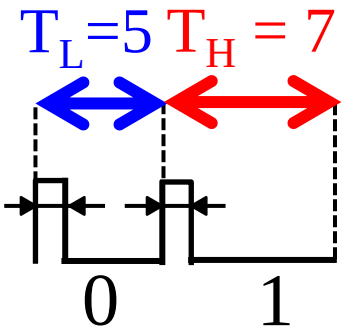
66 dB

in Base & in Each Clock Harmonics

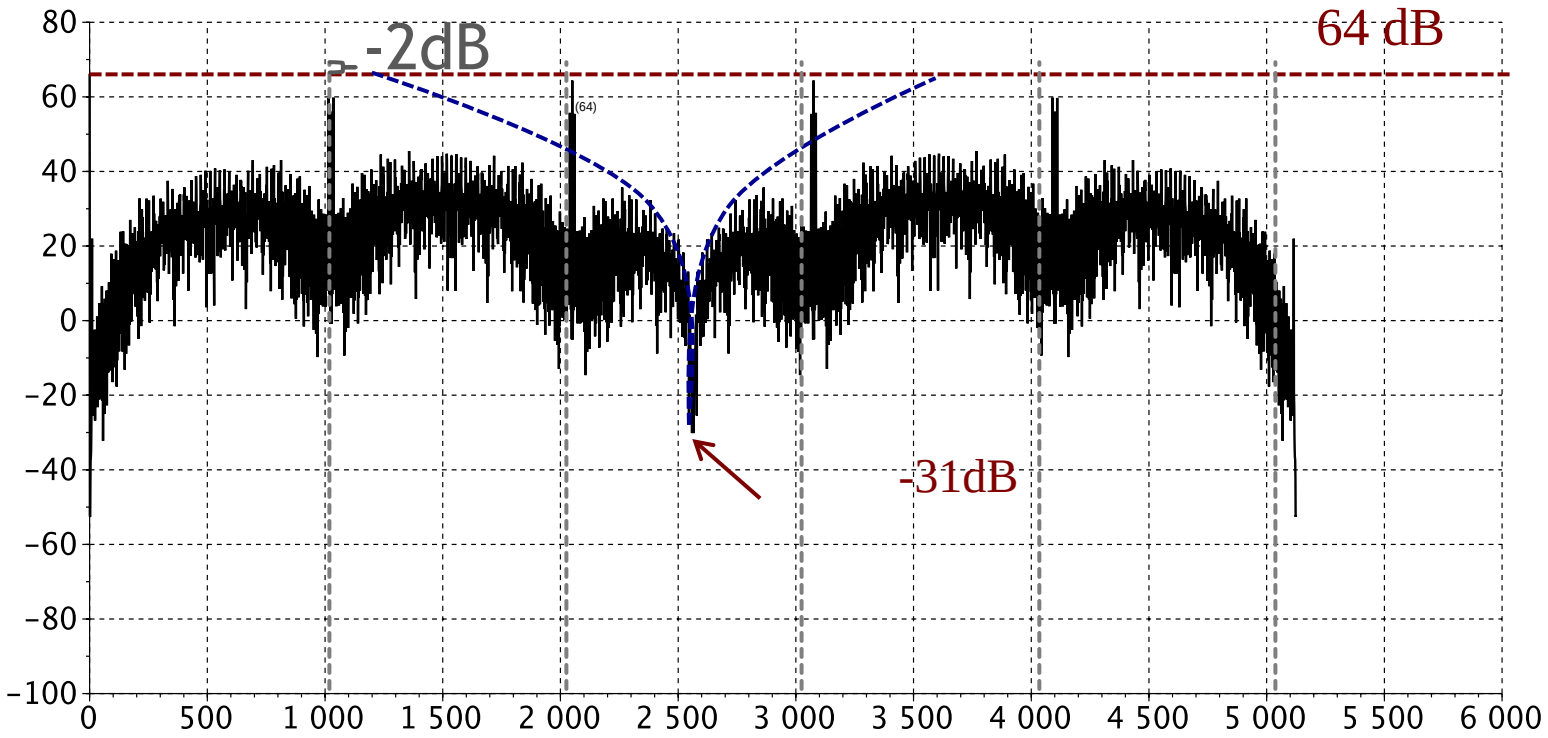


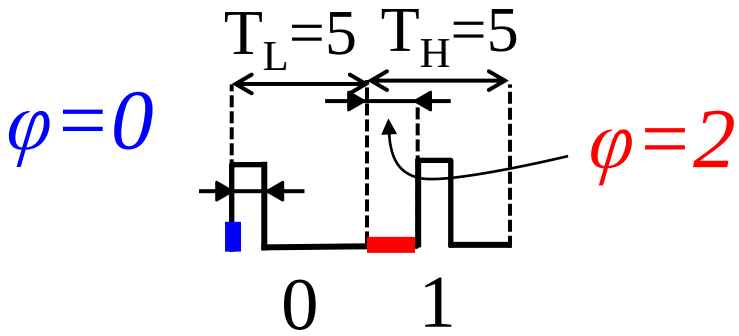
PCMΔΣDTC


80
60
40
20
0
-20
-40
-60
-80
-100
0
1 000
2 000
3 000
4 000
5 000
6 000
7 000
-16dB
50 dB
-35 dB
f

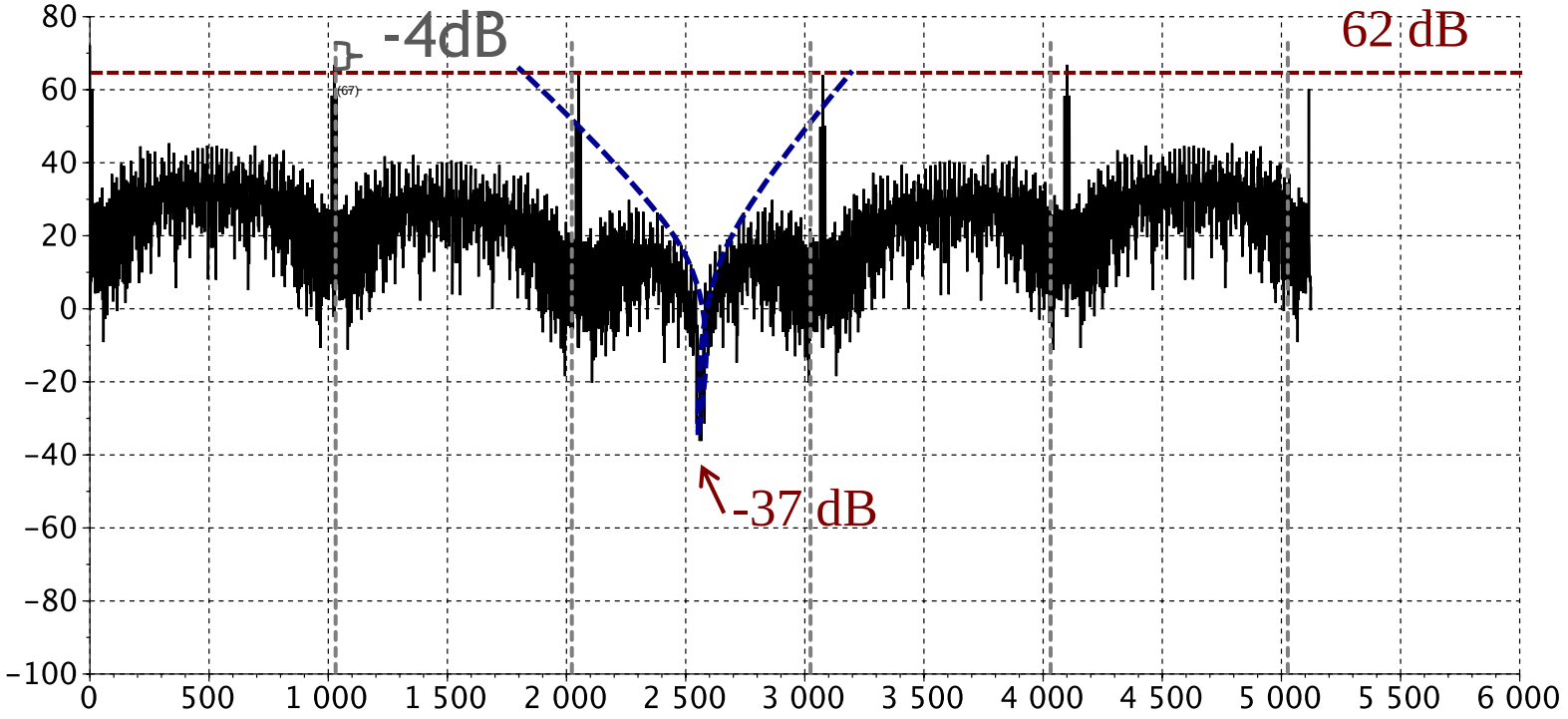

T_L=5 T_H = 7
0
1

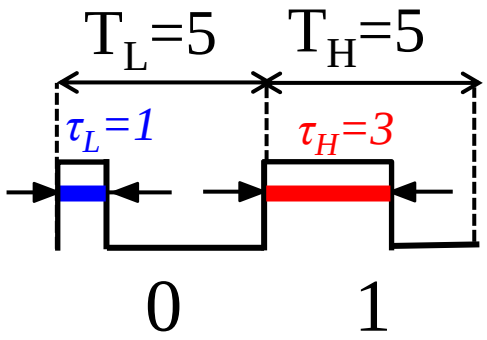
PPMΔΣDTC


64 dB
-2dB
-31dB
80
60
40
20
0
-20
-40
-60
-80
-100
0
500
1 000
1 500
2 000
2 500
3 000
3 500
4 000
4 500
5 000
5 500
6 000
f

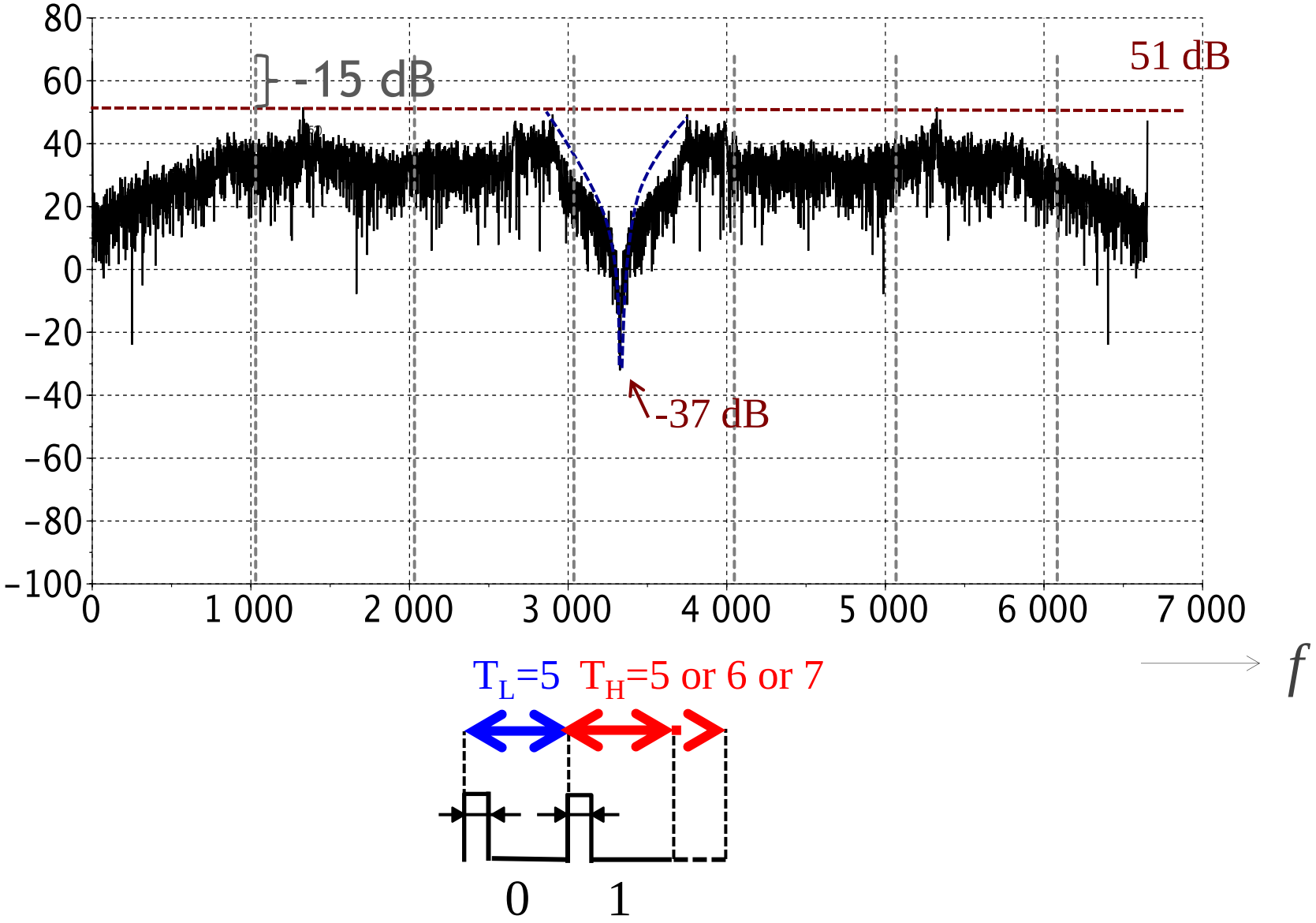

T_L=5 T_H=5
φ=0
φ=2
0
1

PWMΔΣDTC

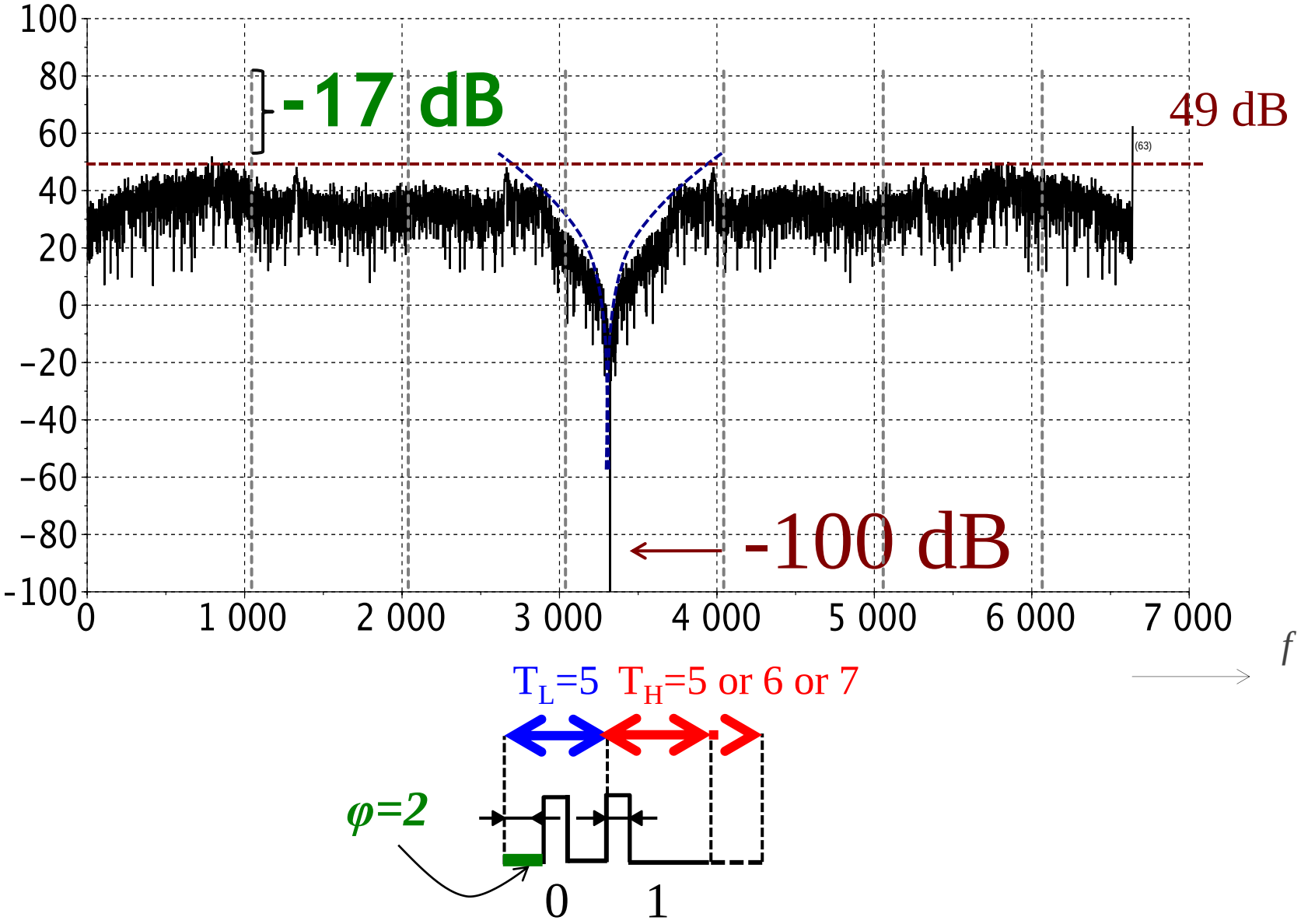

-4dB
62 dB
-37 dB
80
60
40
20
0
−20
−40
−60
−80
−100
0
500
1 000
1 500
2 000
2 500
3 000
3 500
4 000
4 500
5 000
5 500
6 000
f


T_L=5
T_H=5
τ_L=1
τ_H=3
0
1

PRJΔΣDTC


80
60
40
20
0
-20
-40
-60
-80
-100
0
1 000
2 000
3 000
4 000
5 000
6 000
7 000
-15 dB
51 dB
-37 dB
f
T_L=5 T_H=5 or 6 or 7
0
1

Compound DTC: PRJWPΔΣDTC



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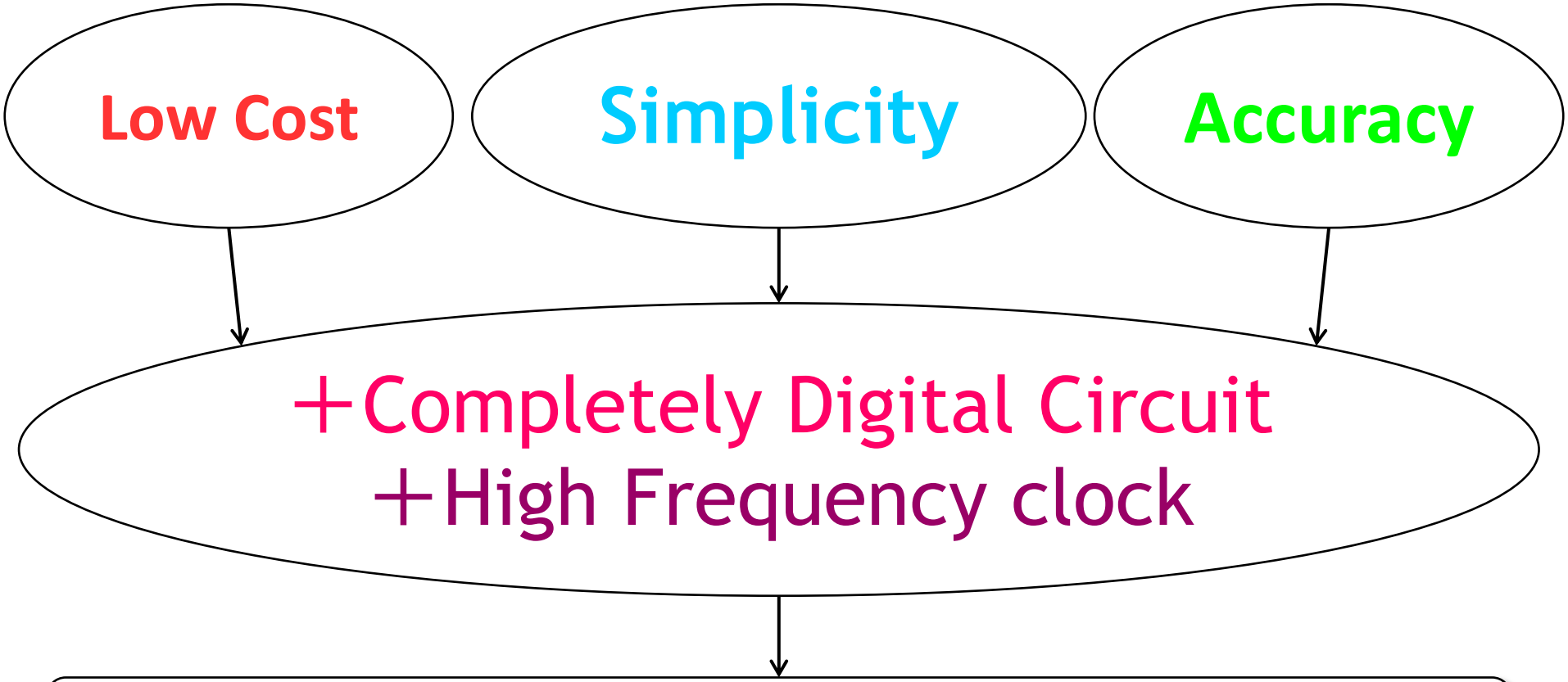
Result


Low Cost
Simplicity
Accuracy
＋Completely Digital Circuit
＋High Frequency clock
Spreading Usage Spectrum of
SSCG With Exclusive Noise Spectrum!

The End

小林先生ありがとう

ご清聴有り難う御座います

Cảm ơn bạn rất nhiều

非常感谢

Thank You Very Much

خیلی ممنون

Muchas gracias

Большое спасибо

Vielen Danken

Presentation

Presentation Start

Presentation

Kobayashi Ring

Conclusion

Presentation

Question and Answer