# Efficient Linearity Self- Calibration Condition with Histogram Method for Time-to-Digital Converter

Pengfei Zhang , Anna Kuwana ,
Shuhei Yamamoto , Yujie Zhao
Yuto Sasaki , Haruo Kobayashi
*Division of Electronics and Informatics*
*Gunma University*
*ROHM Semiconductor*

群馬大学
GUNMA UNIVERSITY

# OUTLINE

- Introduction
- Time to Digital Converter（TDC）
- Self-Calibration
- Histogram Method for TDC
- Conclusions

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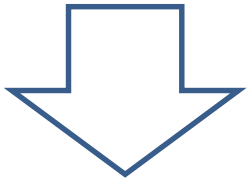
# Introduction

"**Fine time resolution**" and "**high linearity**" TDC (Time to Digital Converter) is the time difference between two digital signals into a digital value



- High linearity TDC

→Self-Calibration circuit

- How to do TDC calibration efficiently

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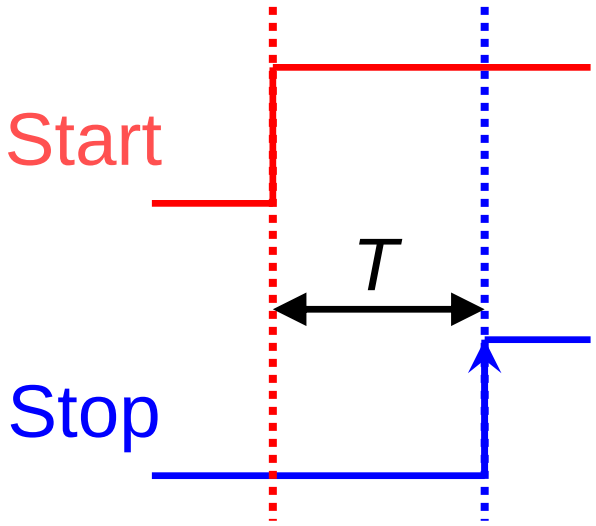
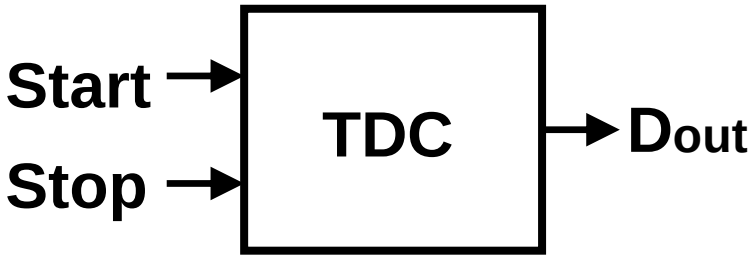
# Time to Digital Converter（TDC）

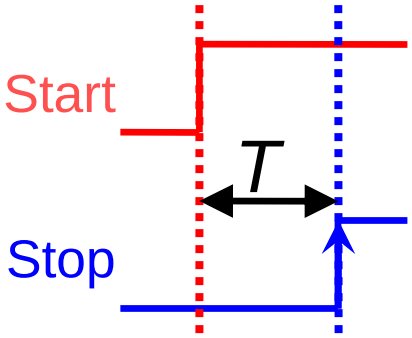


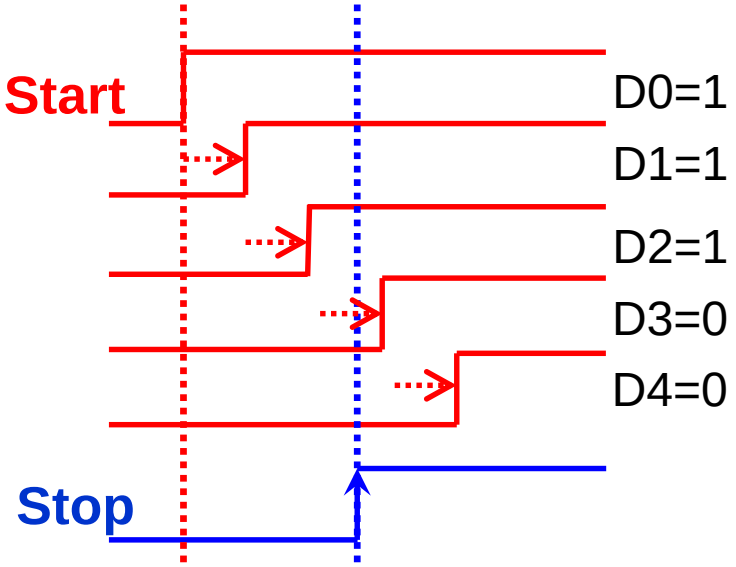

- Time interval → Measurement → Digital value
- Key component of Time-domain analog circuit

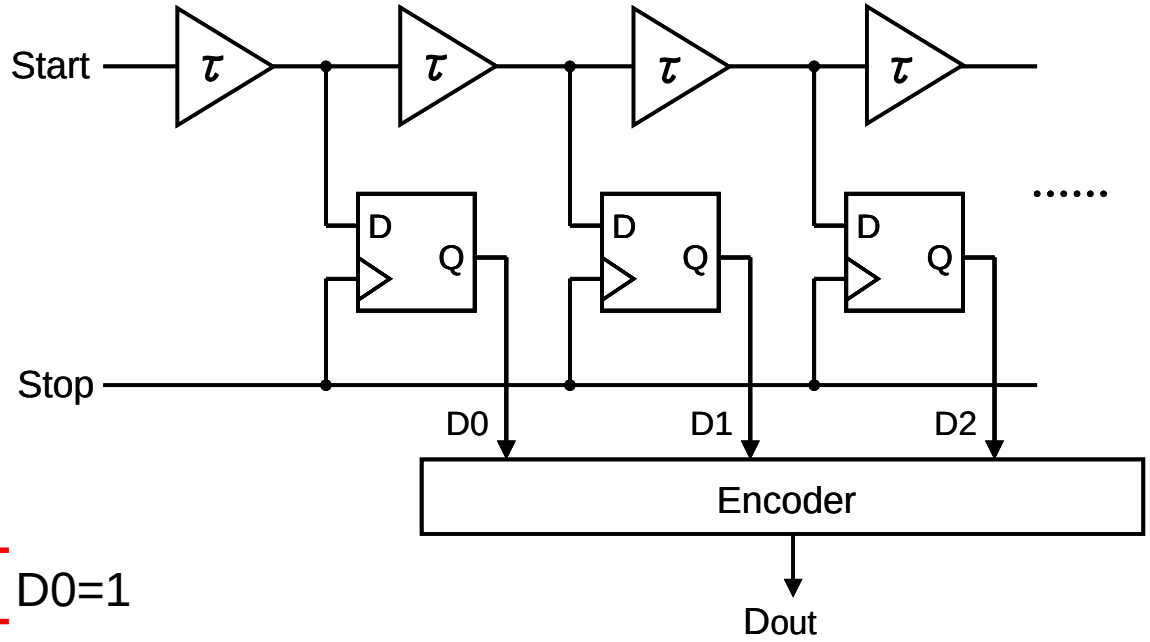
# Time to Digital Converter（TDC）

Time interval → Measurement → Digital value




Timing chart




Encoder

Thermometer code

▼

binary code

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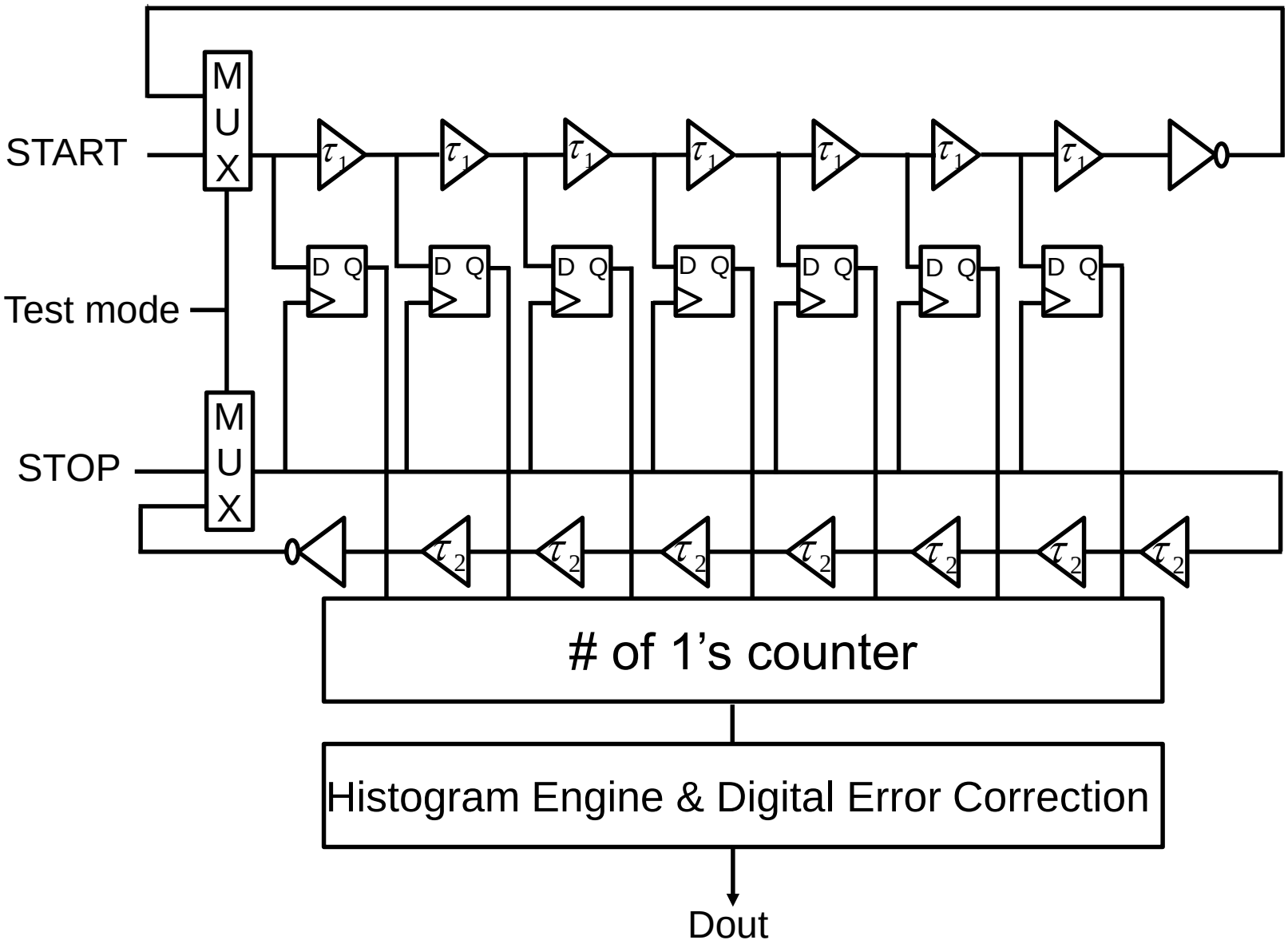
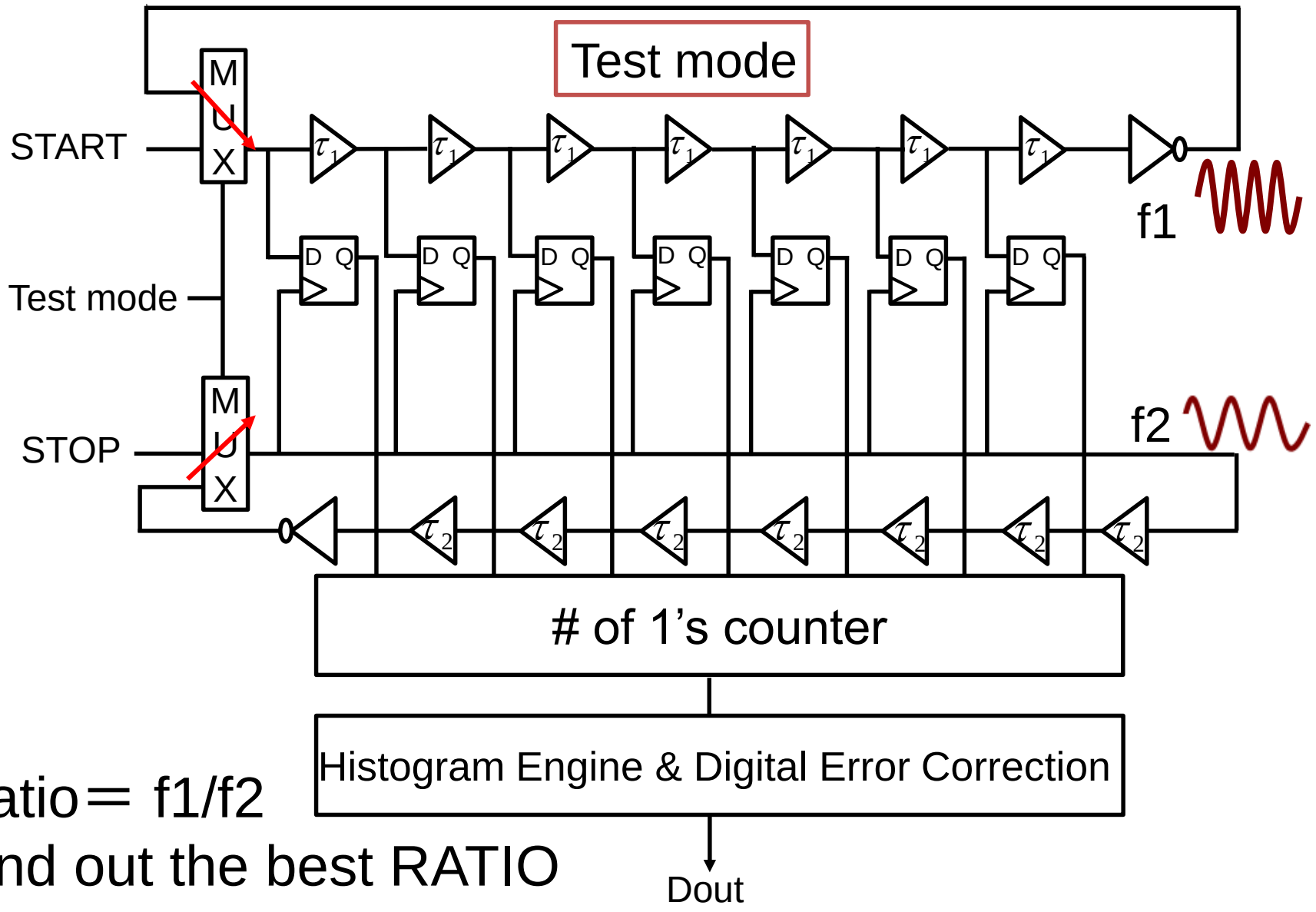
# Proposed TDC Architecture with Self-Calibration



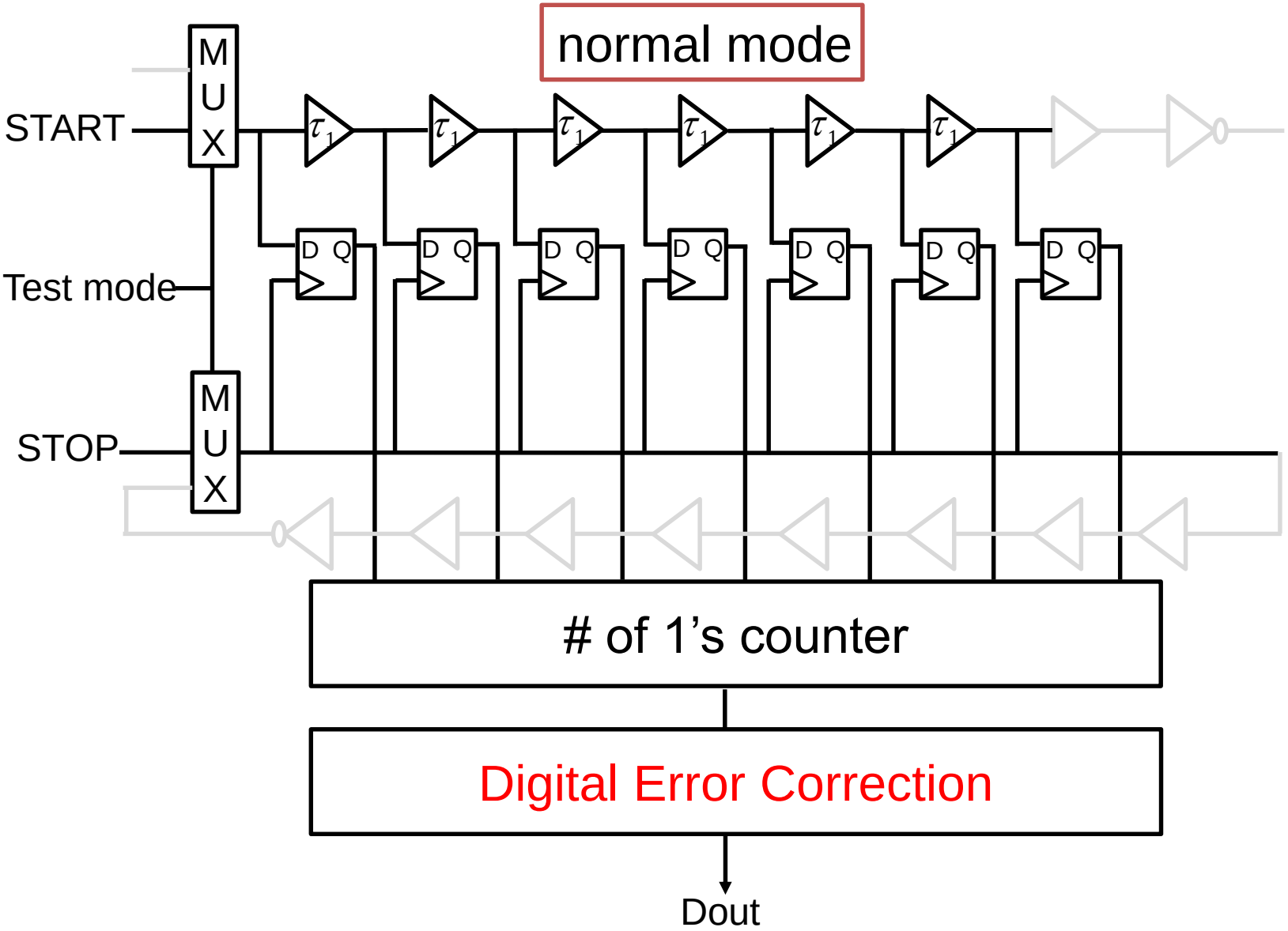
# Self-Calibration Mode



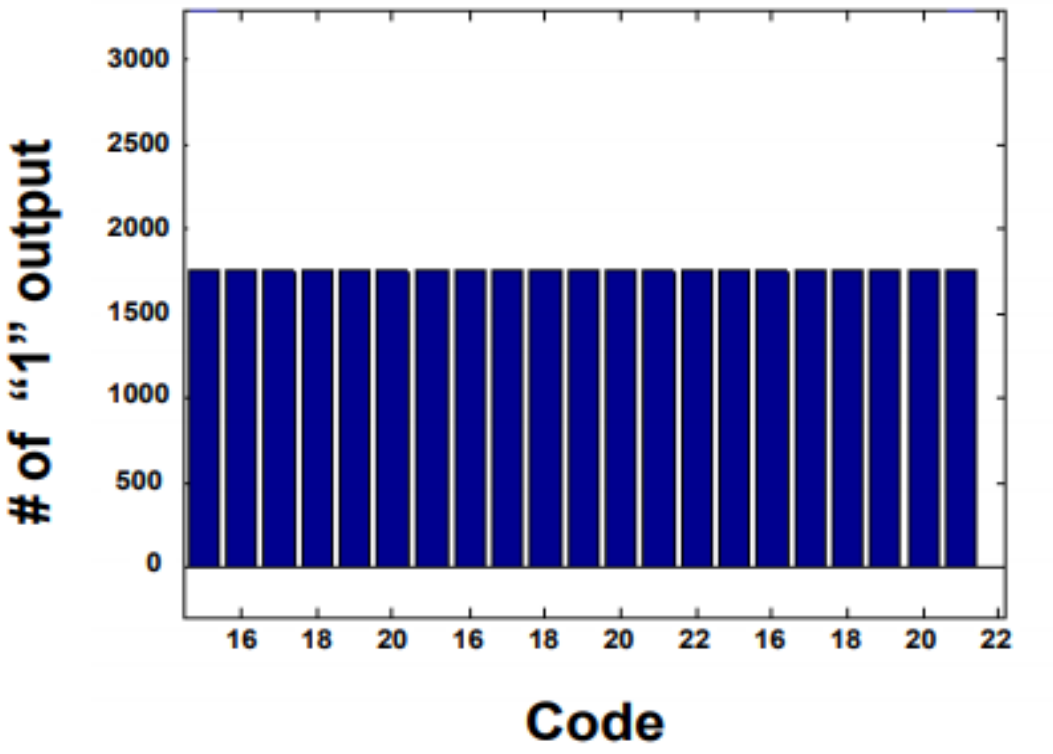

Ratio= f1/f2

Find out the best RATIO

# Normal Operation Mode



# Self-Calibration

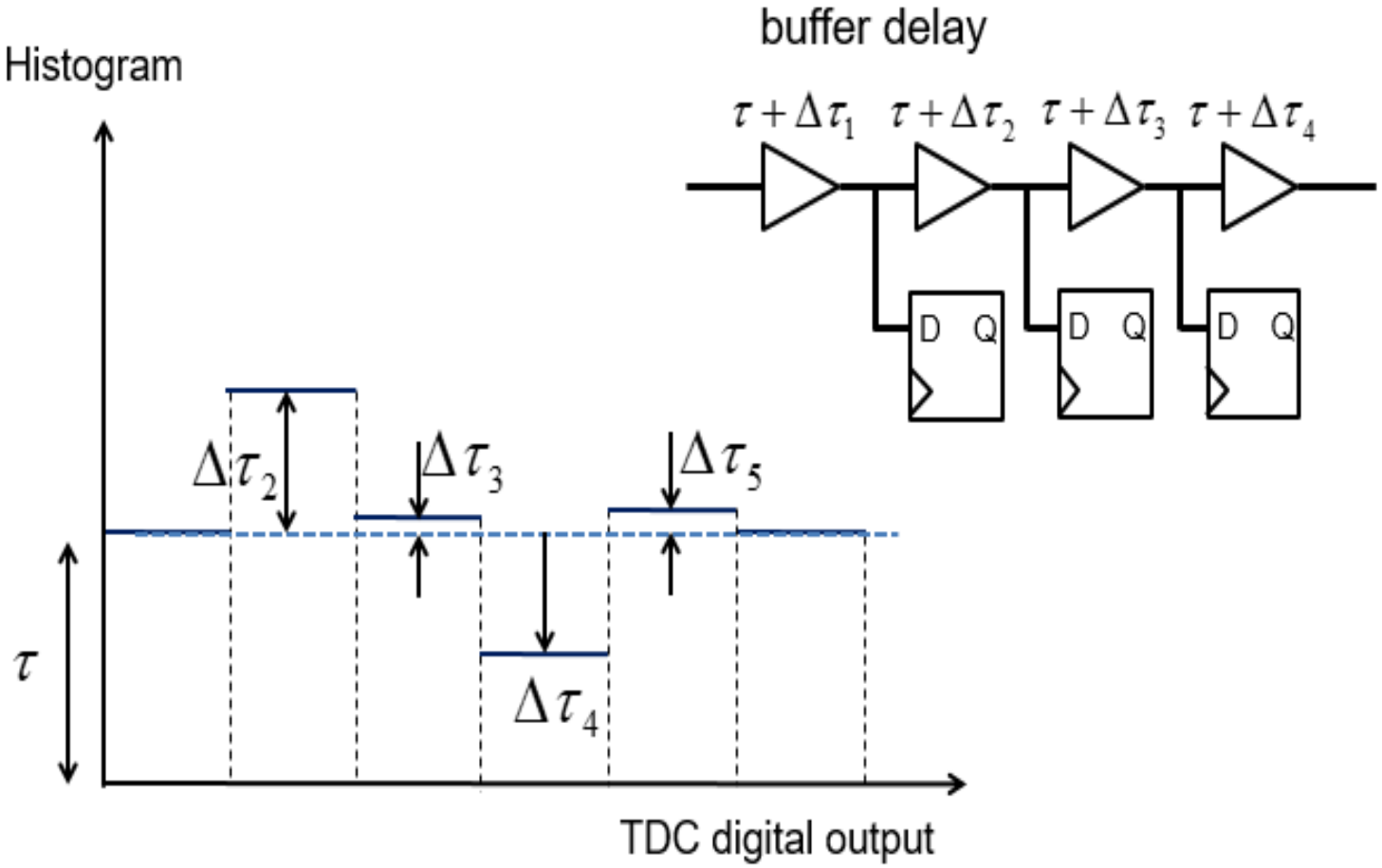



The two oscillators are different from each other and not synchronized

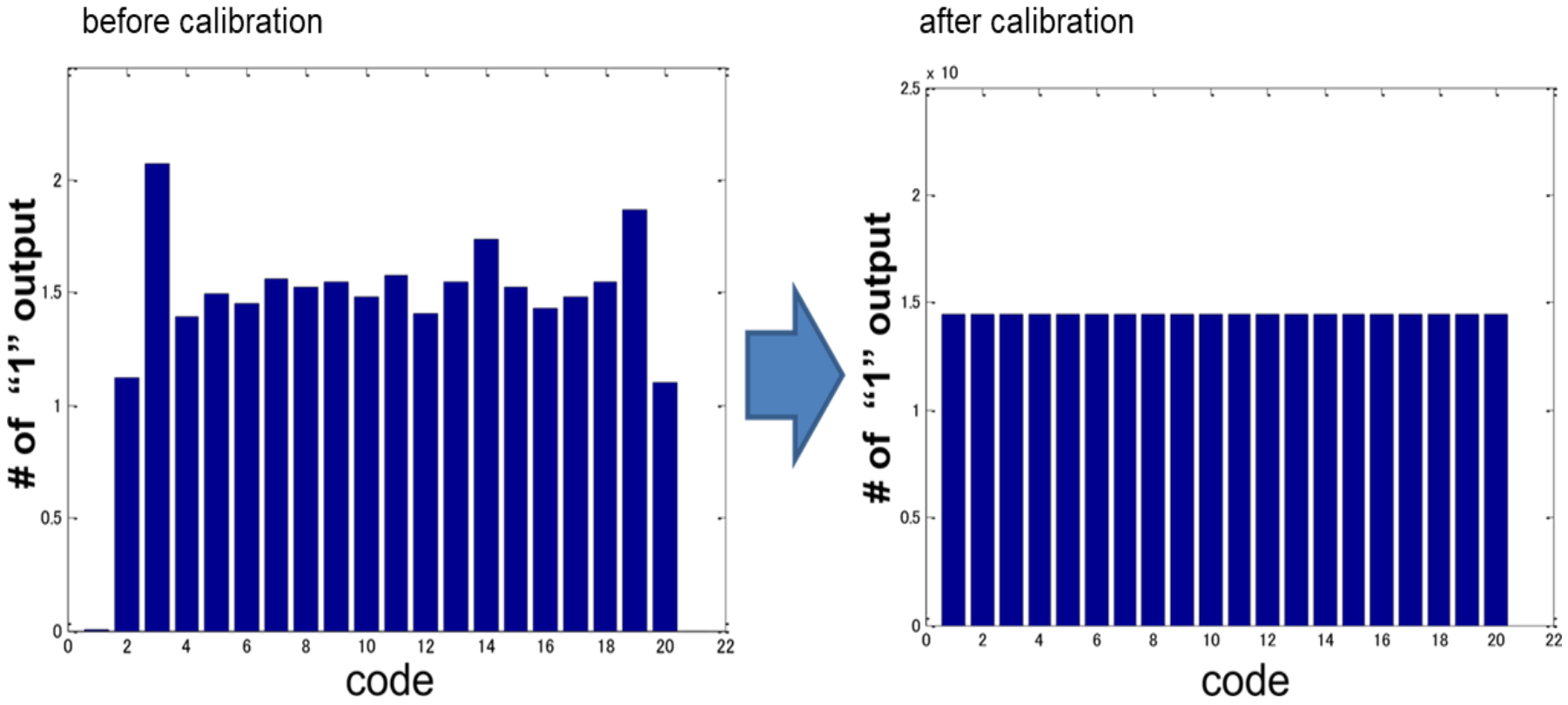
The histograms in all bins will be equal, after collection of a large number of data, if the TDC has perfect linearity

# Self-Calibration

## TDC is non-linear



# Simulation Result of Self-Calibration




Histogram for each bin is the same when the TDC is linear.

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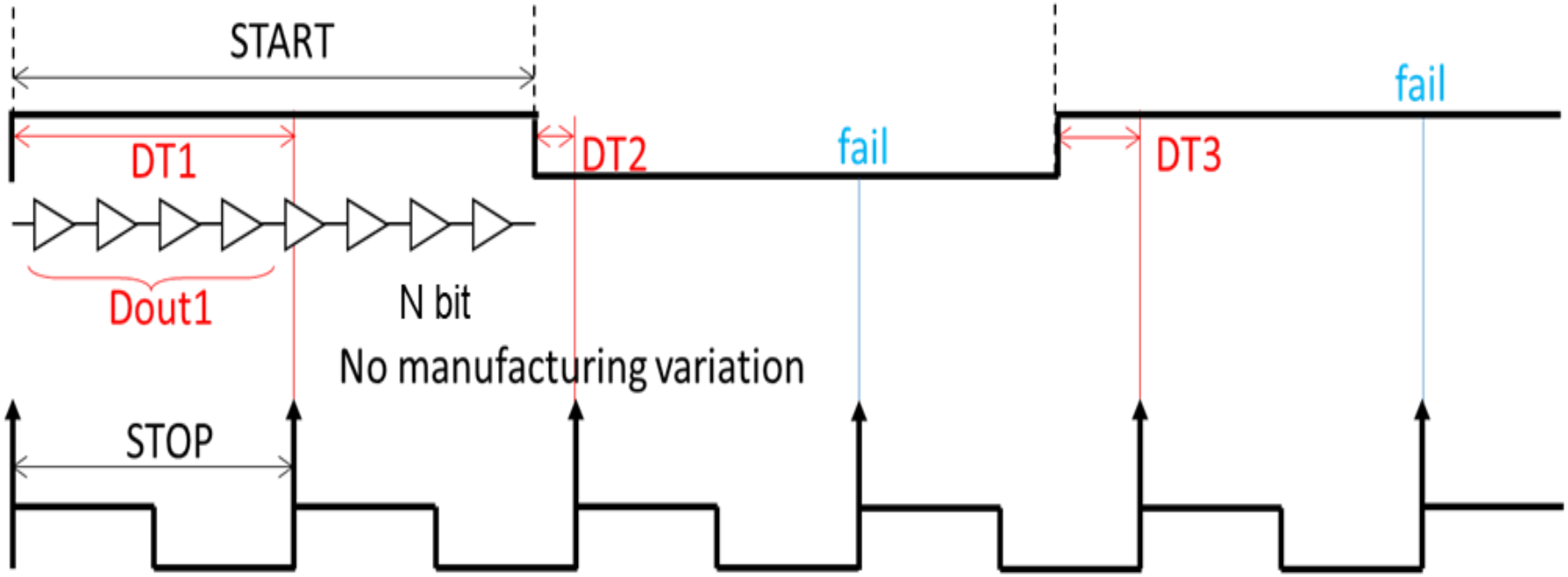
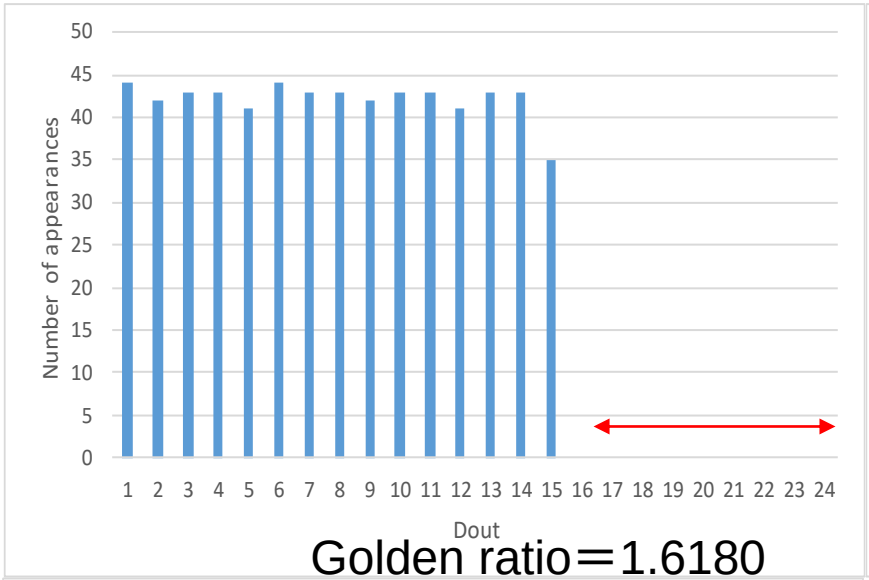
# Definition of simulation condition

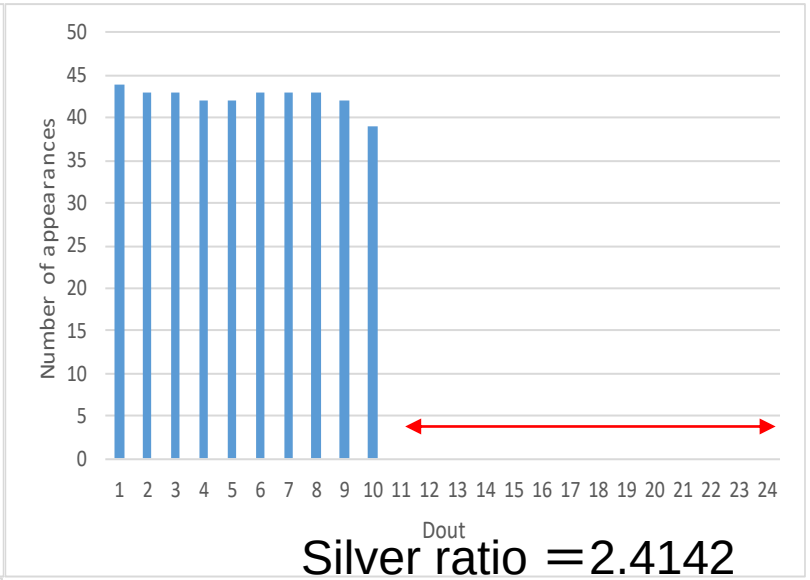



The START is fixed at 1.0, and the STOP is changed between 1.0 and 0.25.
RATIO defined as START/STOP moves in the range of 1.0 to 4.0 in 0.1 increments.

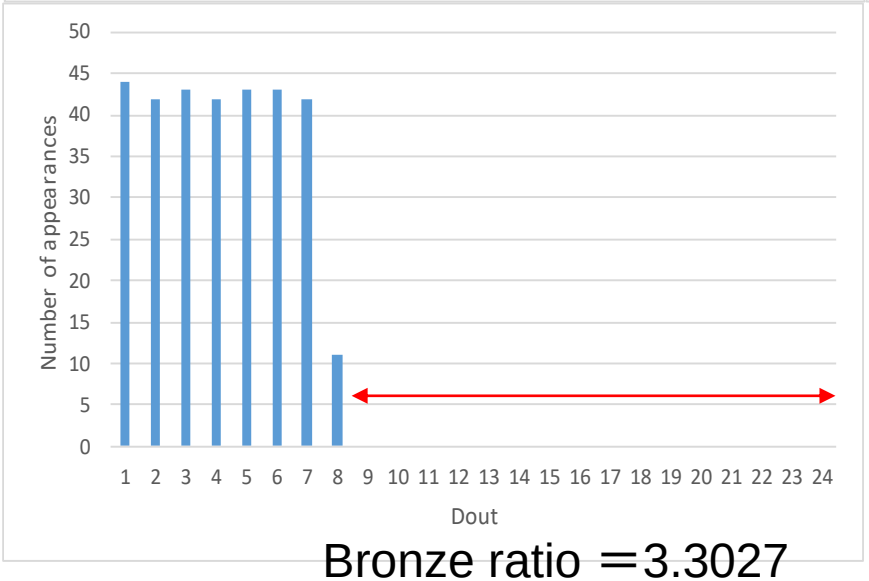
# Frequency of occurrence of values




Golden ratio＝1.6180




Silver ratio ＝2.4142

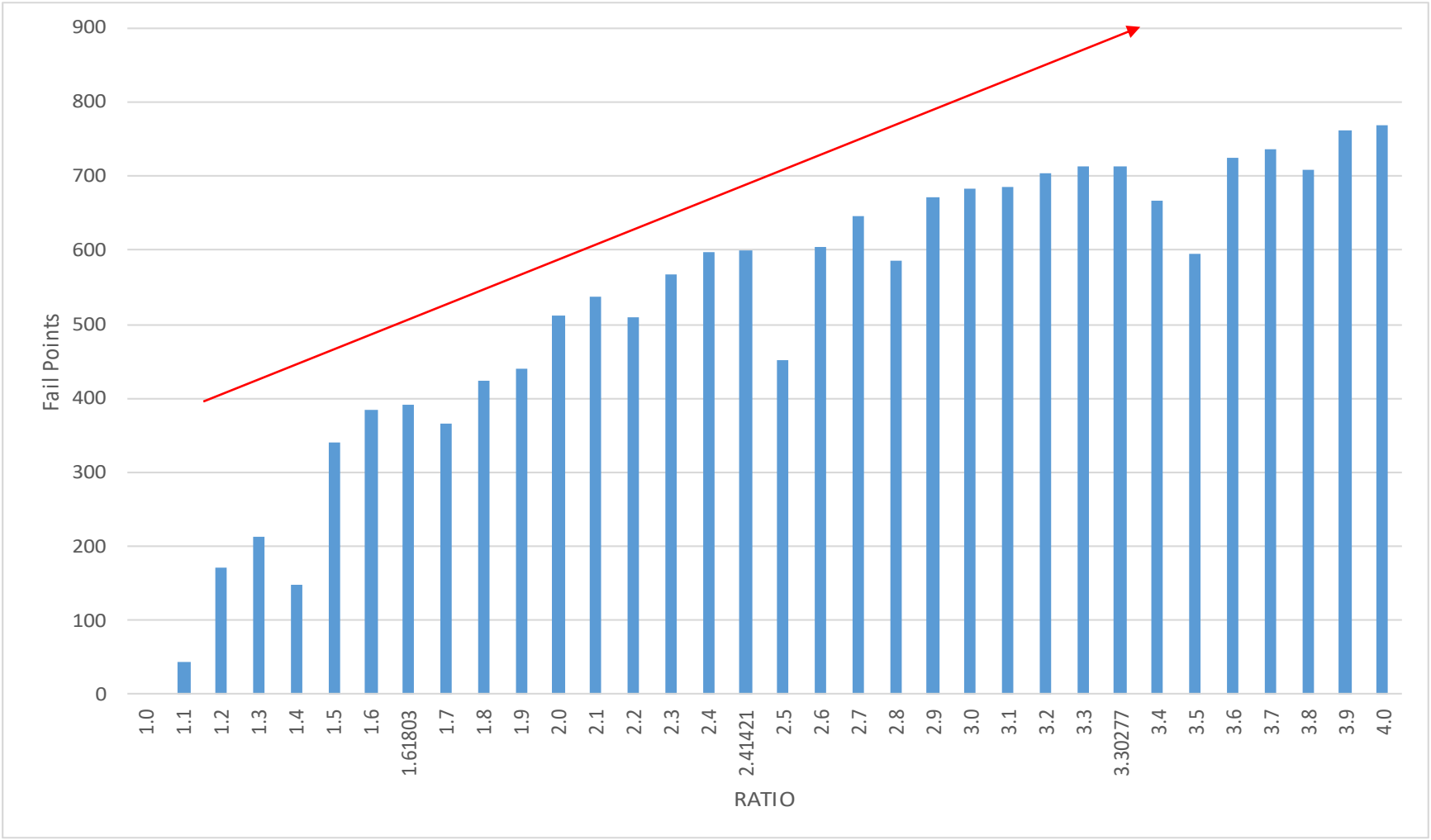



Bronze ratio ＝3.3027

## why？

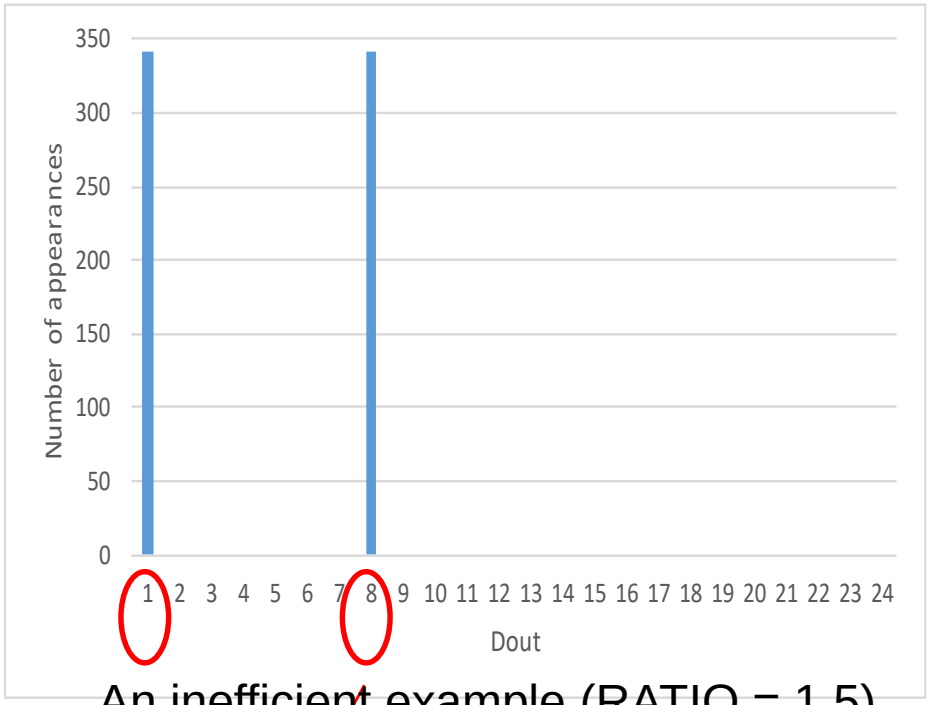
the number of the fail points increases when the RATIO is large

# RATIO vs Fail points.



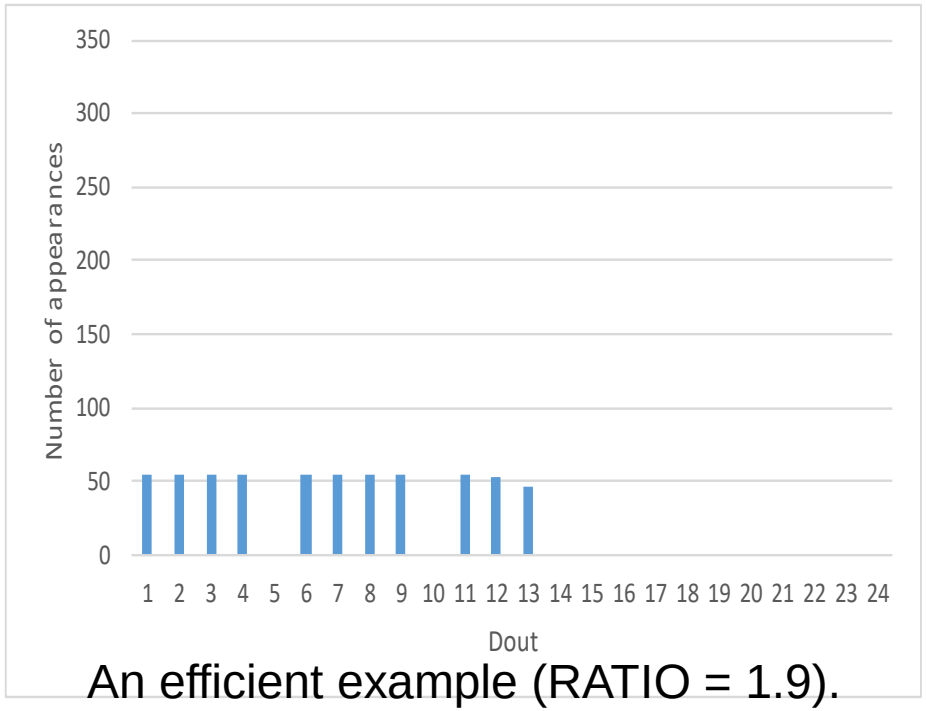

The larger the ratio, the more Fail points

# Frequency of occurrence of values




An inefficient example (RATIO = 1.5).
A

only Dout =1 and 8 output signal




An efficient example (RATIO = 1.9).
B

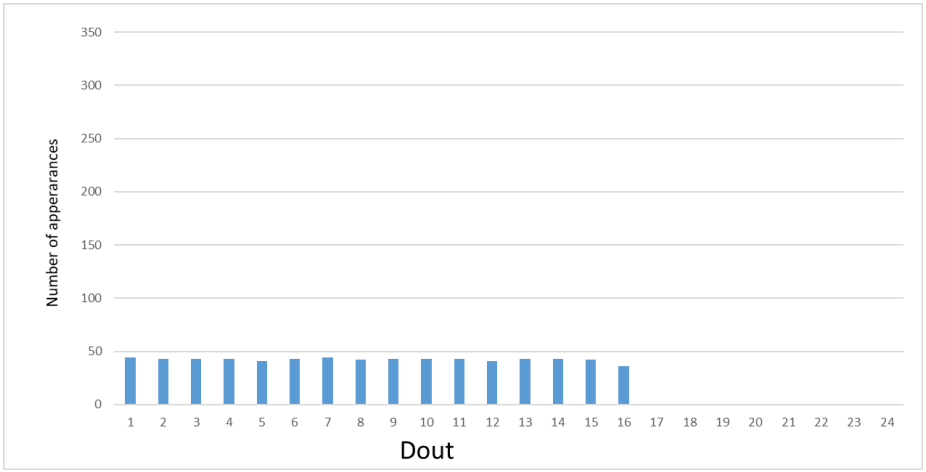
$$\text{RATIO} = \frac{\text{START}}{\text{STOP}} = \frac{f_1}{f_2}$$

Golden RATIO＝1.6180

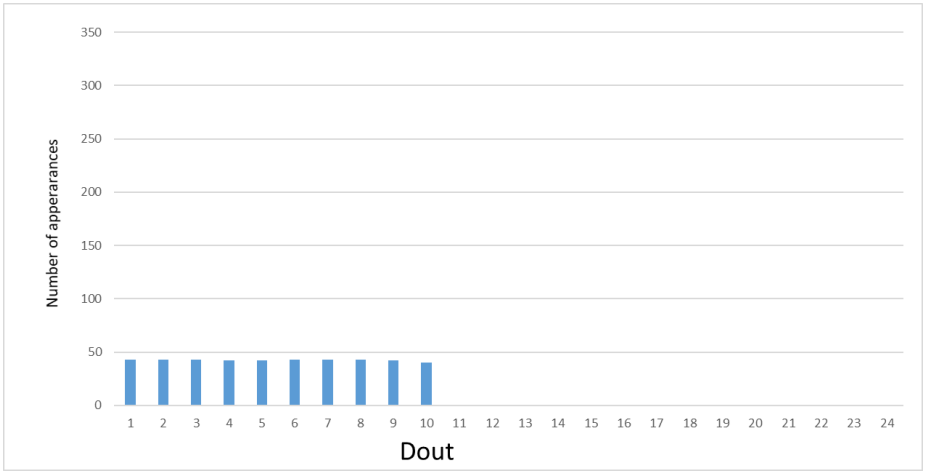
Silver RATIO＝2.4142

Bronze RATIO＝3.3027

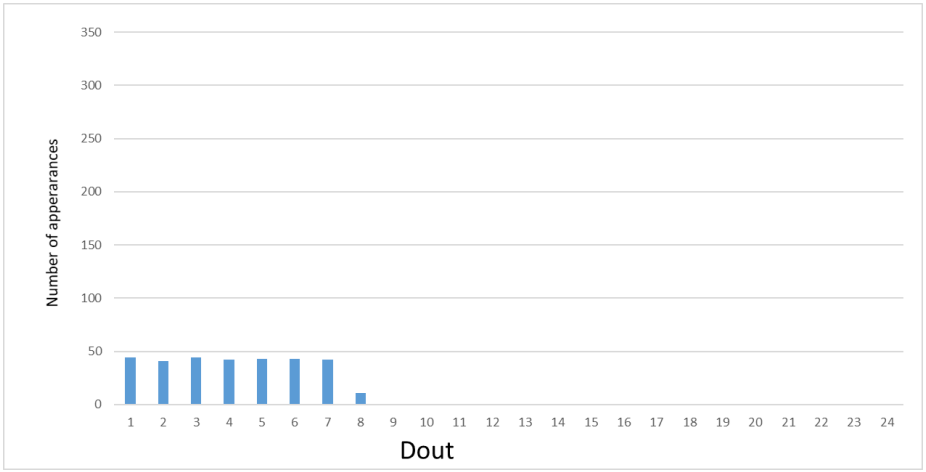
# Frequency of occurrence of values



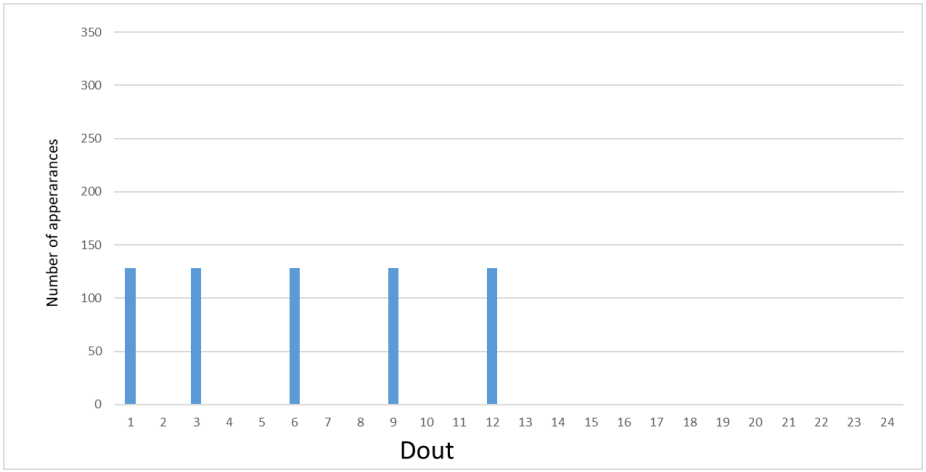

Golden RATIO＝1.6180




Silver RATIO＝2.4142

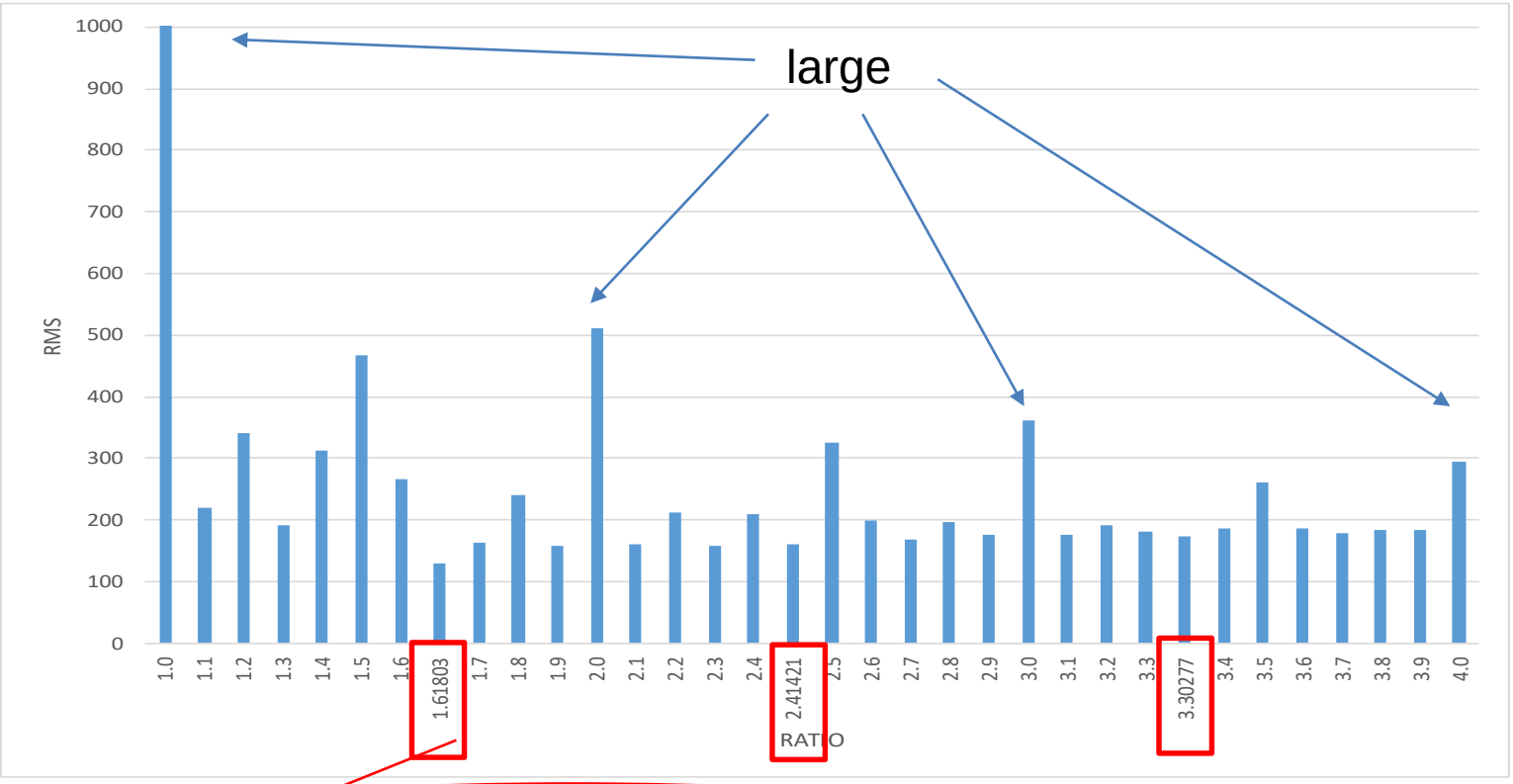



Bronze RATIO＝3.3027




Another example (RATIO = 1.6).

# RATIO VS RMS




TIPS

Root Mean Square (RMS) is defined as the square root of the mean square (the arithmetic mean of the squares of a set of numbers).

RATIO is the golden ratio, RMS is small

$$\text{RMS} = \sqrt{\sum_i (Dout_i - ideal)^2}$$

For example, if N = 4bit (There are $Dout_1$, $Dout_2$, $Dout_3$, $Dout_4$) and the STOP signal is input 20 times, the $ideal$ becomes 5. The ideal histogram has $Dout_1 = Dout_2 = Dout_3 = Dout_4 = 5$ and RMS=0. Smaller RMS means better efficiency.

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# Conclusions

golden ratio
silver ratio
or other metallic ratios

- linearity
- self-calibration
- efficiency

the linearity self-calibration can be done accurately in short time.