Frequency and Period Measurement

\[ l = \frac{vt}{2} \]
Frequency Counter

Input Signal Processor

Decade counter

Memory

Display

Time base

Strobe

Gate

Reset

Input

Gate

Output

\[ f = \frac{N}{t} \]

\( N \) pulses
Time Base

Crystal Oscillator Circuit (OSC) → Frequency Divider → Time base signal

- Non-compensated OSC
- Temp. compensated OSC
- Oven-type OSC

Quartz crystal

High Q ~ 10000
4-bit Binary Counter

1 s
0.1 s
0.01 s
10 Hz
100 Hz
1 kHz

Time base

Crystal Oscillator Circuit (OSC) → Frequency Divider → Time base signal

Logic Diagram of a time base for a frequency counter

State decoder

“0000”
State 0

“0010”
2

“1100”
12

“1110”
14

Reset
Open gate
Close gate
Store
Input Signal Processing

Amplifier

Comparator

Input (Analog)

Output (Digital)

Amplifier

Comparator (Schmitt Trigger)

Input (Analog)

Output (Digital)
Schmitt Trigger: Comparator with Hysteresis

\[ V_{\text{in}} \rightarrow V_{\text{ref}} \rightarrow V_{\text{o}} \]

Trigger level \((V_{\text{ref}})\)

\[ V_{\text{in}} \rightarrow V_{\text{o}} \]

\[ V(1) \]

\[ V(0) \]

\[ V_{\text{TL}} \]

\[ V_{\text{TH}} \]

\[ V_{\text{ref}} \]

\[ V_{\text{in}} \rightarrow V_{\text{o}} \]

\[ V(1) \]

\[ V(0) \]

\[ V_{\text{TL}} \]

\[ V_{\text{TH}} \]

\[ V_{\text{ref}} \]

\[ V_{\text{in}} \rightarrow V_{\text{o}} \]
Period Measurement

Time base $f = 1 \text{ MHz}$

- $1 \mu s$
- $X$ pulses counted

Digital measurement of time period

$T = (X \text{ pulses})(1 \mu s) = X \mu s$

Time base $f = 1 \text{ MHz}$

- $1 \mu s$
- $Y$ pulses counted

Digital measurement of pulse width

$PW = Y \mu s$
Period Measurement (between pulses)

Signal A

Input Signal Processor

Start

Gate

Count

Input Signal Processor

Stop

CLK

1 MHz

1 kHz

100 kHz

10 kHz

Signal B

Core system

Control circuit

A (start)

B (stop)

Gate

CLK

Count

<table>
<thead>
<tr>
<th>S</th>
<th>R</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>Not use</td>
</tr>
<tr>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>No change</td>
</tr>
</tbody>
</table>
Period Measurement (pulse duration)

start stop

Amp

Comparator

S R Q
0 0 No change
0 1 0
1 0 1
1 1 Not use

Control circuit

Gate

Counter

CLK
Period Measurement (pulse period)

- **Input**: A high-pass filter
- **Comparator**: Comparator with an input voltage of 5 V, 0 V
- **Gate**: Gate with logic levels +2.5 V, -2.5 V
- **J and K Flip-Flop**: Set and clear inputs

**Waveforms**:

- **A**: Digital waveform with a period of 5 V and 0 V
- **B**: Digital waveform with a period of +2.5 V and -2.5 V
- **C**: Digital waveform with a period of 5 V and 0 V
- **D**: Digital waveform with a period of 5 V and 0 V
1) Gating error (± 1 count)

- If $f_{in} = 10$ Hz, Gate time = 1 s
  - Display count: $10\pm1$ counts

- If $f_{in} = 1000$ Hz, Gate time = 1 s
  - Display count: $1000\pm1$ counts

If $f_x < f_o$ Period measurement
If $f_x > f_o$ Frequency measurement

$f_c$: clock frequency  $f_x$: unknown frequency
Period meas.: the number of pulses ($N_p$)

$$N_p = \frac{f_c}{f_x}$$

Frequency meas.: with 1 s gate time the number of pulses ($N_f$)

$$N_f = f_x$$

The crossover frequency ($f_o$) $N_p = N_f$

$$\frac{f_c}{f_o} = f_o; f_o = \sqrt{f_c}$$
Measurement Error

2) Time-base Error

- Oscillator calibration errors
- Short-term crystal stability errors (voltage transient, shock, vibrate, temperature)
- Long-term crystal stability errors (aging, deterioration of crystal)

National Institute of Standards and Technology, 60 kHz
Loran-C, a navigation signal at 100 kHz
A frequency counter with an accuracy of ± 1 LSD ± (1×10⁻⁶) is employed to measure frequencies of 100 Hz, 1 MHz, and 100 MHz. Calculate the percentage measurement error in each case.

At \( f = 100 \text{ Hz} \)

\[
\text{error} = \pm (1 \text{ count} \pm 100 \text{ Hz} \times 10^{-6})
\]

\[
= \pm (1 \text{ count} \pm 1 \times 10^{-4} \text{ count})
\]

\[
\approx \pm 1 \text{ count}
\]

% error = \[
\pm \left( \frac{1}{100 \text{ Hz}} \times 100\% \right)
\]

\[
= \pm 1\%
\]

At \( f = 1000 \text{ Hz} \)

\[
\text{error} = \pm (1 \text{ count} \pm 1 \text{ MHz} \times 10^{-6})
\]

\[
= \pm (1 \text{ count} \pm 1 \text{ count})
\]

\[
= \pm 2 \text{ count}
\]

% error = \[
\pm \left( \frac{2}{1 \text{ MHz}} \times 100\% \right)
\]

\[
= \pm 2 \times 10^{-4} \%
\]
At $f = 100$ MHz
error = $\pm (1 \text{ count } \pm 100 \text{ MHz} \times 10^{-6})$
= $\pm (1 \text{ count } \pm 100 \text{ count})$
= $\pm 101 \text{ count}$

$\% \text{ error} = \pm \left( \frac{101}{100 \text{ MHz}} \times 100\% \right)$
= $\pm 1.01 \times 10^{-4} \%$
3) Trigger Level Error (Noise)
   - Use large signal amplitudes and fast rise time

Maximum accuracy could be obtained by

1) use period measurement if $f_x < f_c$
   use frequency measurement if $f_x > f_c$
2) Calibrate regularly to prevent long-term stability error
3) Reduce trigger level error in time measurement by using large signal and fast rise time
Hysteresis band

'clean' sine wave crosses the hysteresis band twice during each cycle - triggering counting circuits once per cycle

Noisy sine wave crosses the hysteresis band more than twice during each cycle - produce counting error

Attenuated noisy wave form crosses the hysteresis band twice during each cycle

A low amplitude input pulse can produce errors in pulse width measurement

Amplification of the input pulse minimizes the pulse width measurement
Ex จงหา resolution และค่าความถี่สูงสุดที่สามารถแสดงผลได้ในเครื่องวัด
ความถี่ที่มีการแสดงผลแบบ 7 หลัก ถ้าเวลาของสัญญาณเกิดถึ่งไวที่ 1
วินาที (resolution = 1 Hz, Max. freq. = 9,999,999 Hz)

Ex เครื่องวัดความถี่เครื่องหนึ่งมีความผิดพลาดจากการนับ ±1 ครั้ง (±1 count)
และมีความผิดพลาดจากฐานเวลา 5 ส่วนในล้านส่วน (ppm: part per million)
จงหาค่าเปอร์เซ็นต์ความผิดพลาดเมื่อใช้วัดความถี่ 1 kHz

ความผิดพลาดรวมเท่ากับผลรวมของความผิดพลาดทั้งสอง
ความผิดพลาด = ± (1 count + 1 kHz x 5 ppm)
= ± (1 count + 0.005 count)
ค่าเปอร์เซ็นต์ความผิดพลาด = ± \( \frac{1.005}{1000} \times 100 = 0.1\% \)
Specifications of a freq./period Measurement

Frequency mode
Range: DC to 50 MHz
Gate time: Manual 1 ms to 100 s in decade step
Automatic up 1 s gate time

Period mode
Range: 1 μs to 1 s unit in μs

Duration mode
Range: 100 ns to 10^4 s
Inputs: 2 channels for start signal and 1 channel for stop signal
Extending the frequency range of a counter

- **Prescaler (upto 1.5 GHz)**

  - Reduce resolution but can be improved by extending gate time

- **Heterodyne Technique**
Homodyne and Heterodyne technique

\[ \frac{1}{2} \{ \cos [2\pi(f_2-f_1)]t + \cos [2\pi(f_2+f_1)]t \} \]

If \( f_1 = f_2 \); Homodyne

Time domain

Frequency domain

Amplitude

0

\( f_1 \)

\( 2f_1 \)

Amplitude

0

0.2

0.4

0.6

0.8

1

0.2

0.4

0.6

0.8

1

0.5

1

1.5

2

0.5

1

1.5

2

0

f

f

difference

sum
Homodyne and Heterodyne technique

If $f_1 \neq f_2$; Heterodyne

Time domain

Frequency domain
Automatic Heterodyne Unit

Ex input freq. 2.1 GHz
1.5 ± 2.1 = 3.6, 0.6 GHz
2.0 ± 2.1 = 4.1, 0.1 GHz

1.0 GHz
1.5 GHz
2.0 GHz
2.5 GHz
3.0 GHz
3.5 GHz

Harmonic Generator

Switch

Low Pass Filter

Control logic

Level Detector

Input 500 MHz - 4 GHz

Level Detector

To 500 MHz Counter

ft = 500 MHz
Accuracy

- Prescaler

Displayed freq. = \( \frac{f_{\text{in}}}{N} t \)

- Accuracy \( \propto t \)

Exactly the same as the counter without a prescaler

- Heterodyne Technique

Gate time, \( t = \frac{Q}{f_c} \)

Input freq., \( f_{\text{in}} = f_{\text{in}}' \pm Nf_c \)

Displayed freq. = \( f_{\text{in}} \frac{Q}{f_c} = f_{\text{in}}' \frac{Q}{f_c} \pm NQ = f_{\text{in}}' t \pm NQ \)

Accuracy \( \propto t; (NQ \text{ is constant}) \)
Opening and Closing gate are controlled from either the input signal or the internal clock.

Computer will help to determine whether freq./period will be performed.