Università degli Studi di Padova

Time and frequency measurements

Lecture #14

Electronic measurements

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Time and frequency measurements

- **Measurement of time intervals**
  - Measurement of periodic signals
  - Measurement of the delay between two signals
  - Phase shift measurement
  - Measurement of the rise and fall times of steep edges

- **Measurement of frequencies**
  - Characterization of signal generators, voltage-controlled oscillators, etc…
  - Analysis of signal sources associating the information content to frequency

- **Measurements of time delay by means of ad-hoc sensors and transducers**

Time and frequency measurements

- Identification of certain **reference points** on the analysed signal → **Events**

- **Measurement of the period** → **Events:** beginning and ending of the period
- **Measurement of the rise time** → **Events:** instants at which the signal reaches conventionally defined amplitude values

- Set of circuits which extract the events of interest from the input signals

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Crossing of a given amplitude level

Time and frequency measurements

- Measurement is made by **direct comparison with the instrument's internal reference**

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Generation of time intervals of constant and known duration

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Determination of elapsed time by counting them

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Counter

Counter


Agilent
53220A
Universal Frequency Counter/Timer
LXI
50%
AC 1MΩ 5V
CH 1 Frequency
Gate
10.020 969 383 MHz
Vpp: 2.00 V
Vmin: −990mV
Vmax: 1.01 V
Freq / Period Key
Freq
Freq Ratio
Period
Measure
View
System
Auto Scale
Digits
Preset
Freq Period
Graph
Utility
Time Interval
Math
Help
Totalize
Data Log
Shift
Gate
1
2
3
Trigger
Back Local

Main components of a counter

- Input circuits
- Time and frequency reference
- Gate circuit
- Logic circuits and counting elements
- Control circuits
- Visualization tools

Input circuits

- At least **two input channels**, the use of which can be coordinated
- Each channel has **its own independent input circuits**

- **Signal conditioning circuit** → Similar to other measurement instruments
  - Amplification
  - Attenuation
  - Impedance matching

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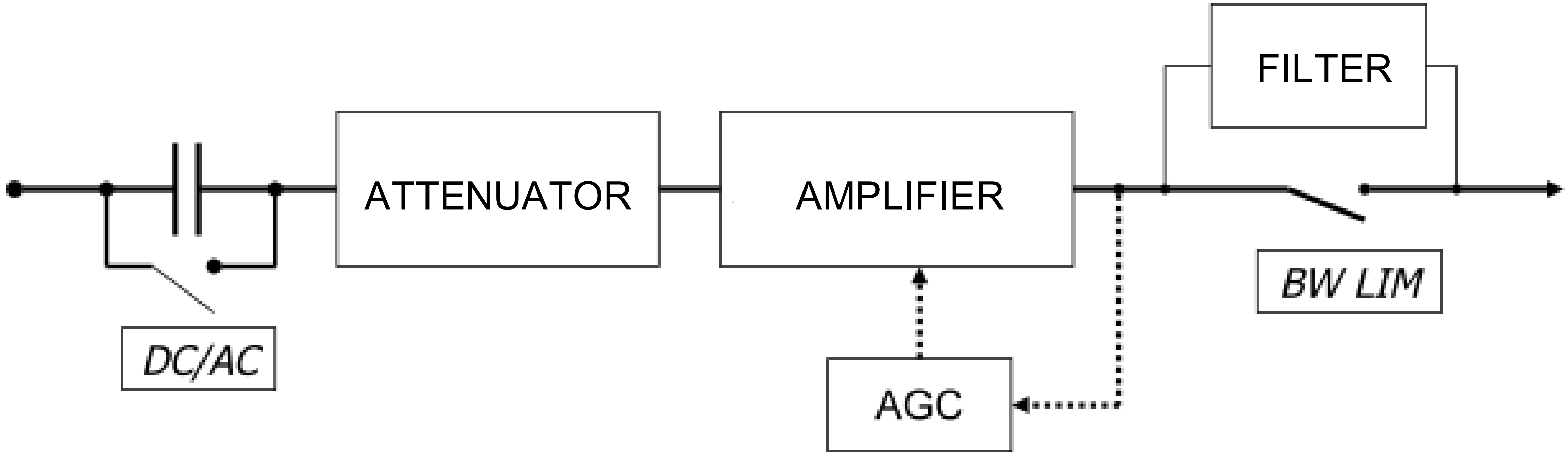
  - **Normalization circuits**

Input circuits



Input circuits

- **AC/DC switch** (Series capacitor): AC coupling
- Amplifiers and attenuators:
  - Extremely wide bandwidth
  - High gain
  - Stable over time and temperature changes
  - Low noise level
  - Uniformity of behaviour
- **Low pass filter (BW LIM):** when measuring signals at frequencies significantly lower than the maximum one, it can reduce the effects of broadband noise

Input circuits

- **Shaping circuit:** provides a signal that retains the time information of the input signal while being different in form → **Comparator with hysteresis**

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- **Trigger**: there is a switching edge any time the input signal reaches a threshold voltage
- The information concerning the events of interest is associated with the switching of a signal

- Maximum frequency of the counter → switching speed of the trigger
- The most important condition to be fulfilled in this case is the **permanence**

Input circuits

- **Rise time measurements:** the ability to precisely establish the threshold level also becomes important → The set level needs to be **verified from the outside**
- Counters often have an **output** on which the DC voltage of the trigger level is present

- Comparator without hysteresis → Impact of noise → Spurious switching

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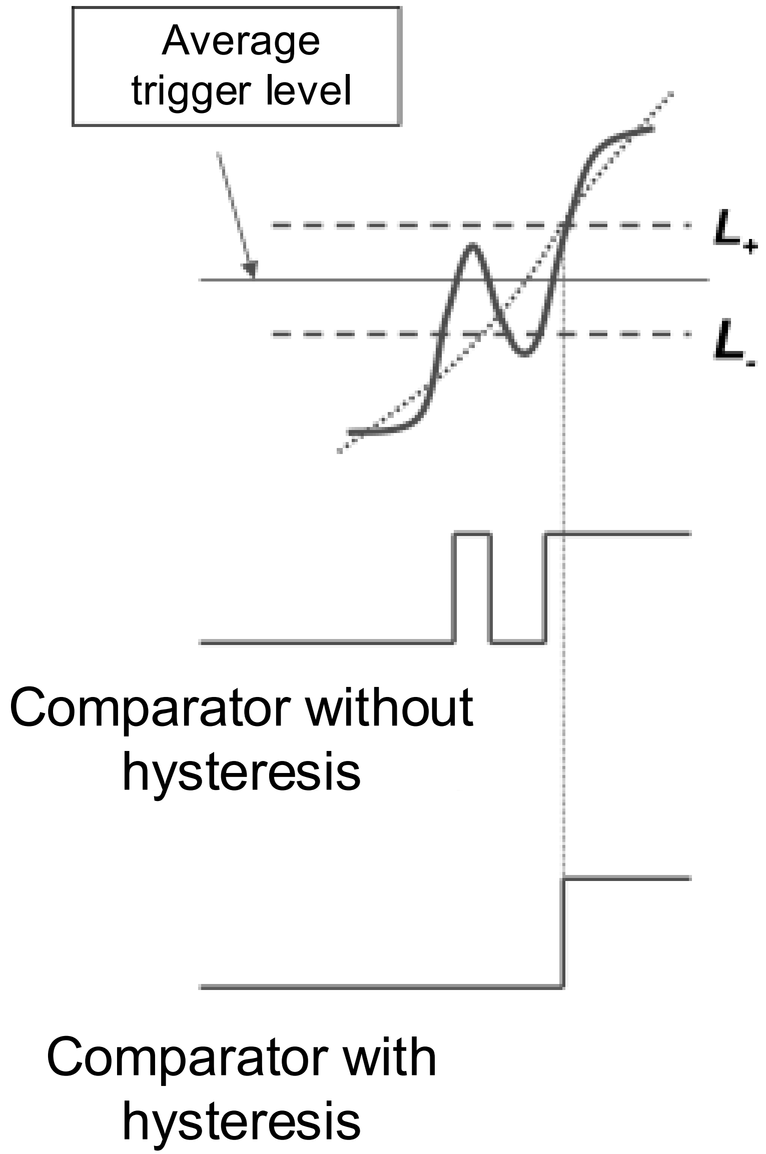
Introduction of a **hysteresis** into the input-output characteristic of the comparator

Input circuits



Input circuits

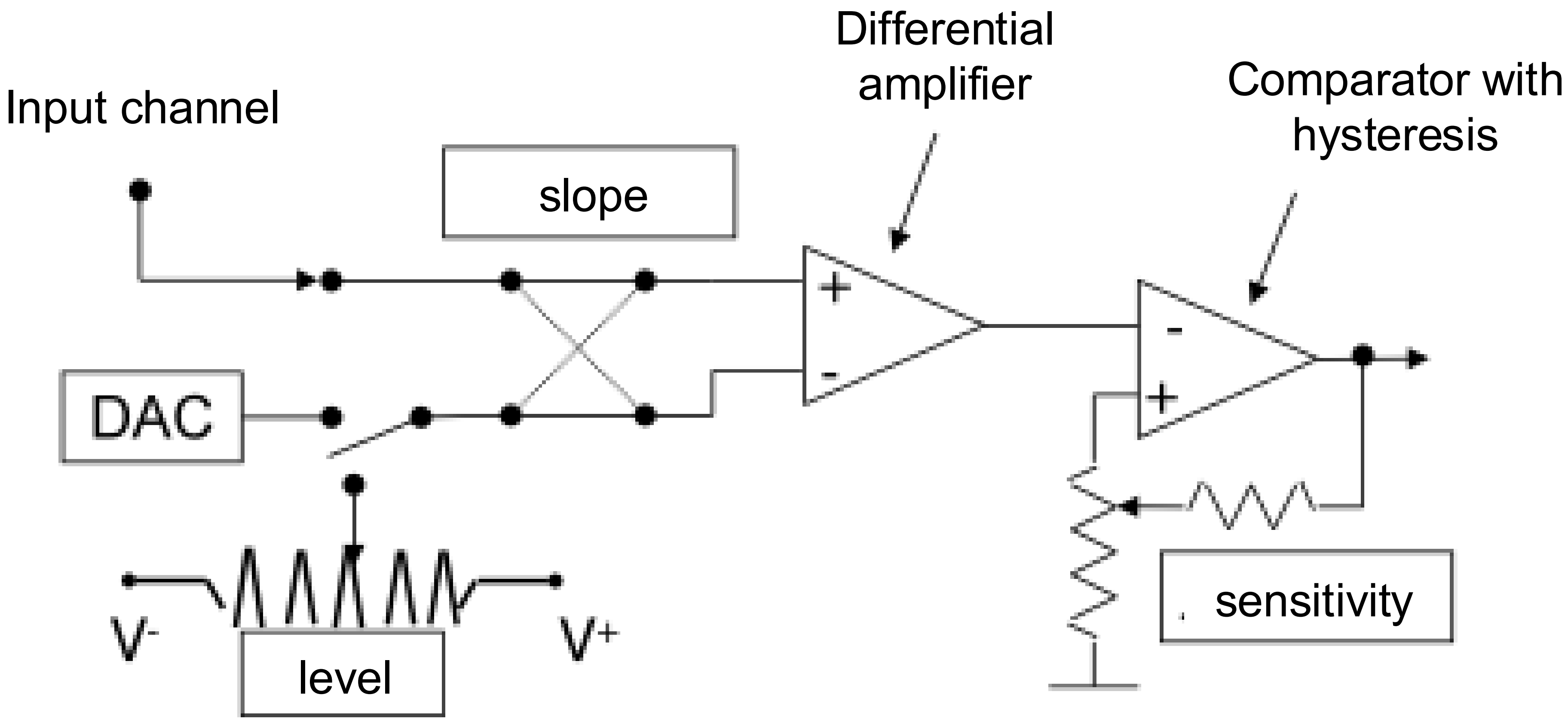
- The peak-to-peak amplitude of the input signal must be greater than the amplitude of the hysteresis band
- Command adjusting hysteresis → **Sensitivity** command

- **Sensitivity**: rms value of a sinusoidal signal whose peak-to-peak amplitude is equal to the difference between the two thresholds:

$$\text{sensitivity} = \frac{L^{+} - L^{-}}{2 \cdot \sqrt{2}}$$

Input circuits

Signal shaping circuit



Frequency reference and time base

- **Time base**: sets the fundamental limits of accuracy
- **Quartz cristal** resonant element: oscillation frequency F_R between 1 and 10 MHz
- **Minimization** of temperature influence (oven oscillators)
- Avoiding loading effects → **Buffer** (impedance separator)
- Sinusoid → Converted in a **square wave**

- Factors of **uncertainty**:
  - Fluctuations in the supply voltage
  - Short-term variations
  - Variations over time

→ **10^{-6}**

Gate circuit

- Enables the counting of events:
  - Taken from the input signal
  - Provided, at constant intervals, by the internal reference

- Start signal: opening of the gate
- Stop signal: closing of the gate

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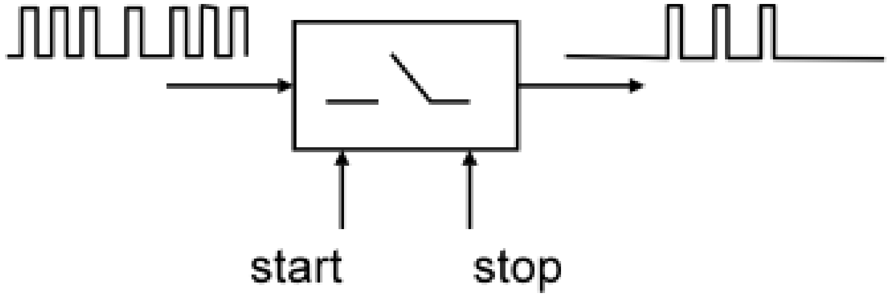
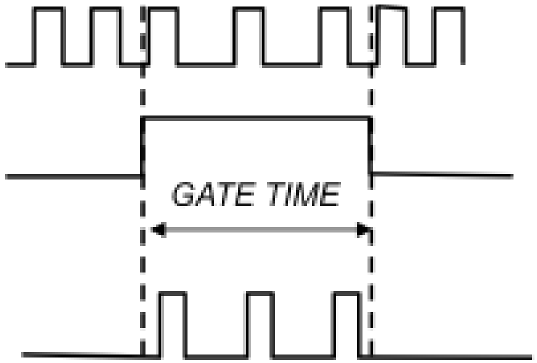
- Time interval $T_{ON} \rightarrow$ **Gate time**
- **Two inputs:**
  - One for the **signal to be sent to the counter**
  - One for the **command signal**

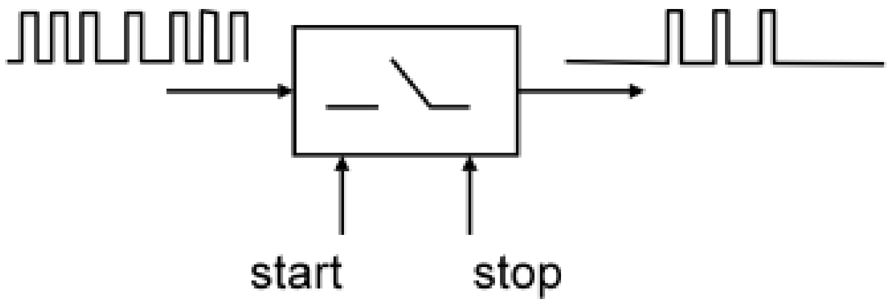
Gate circuit

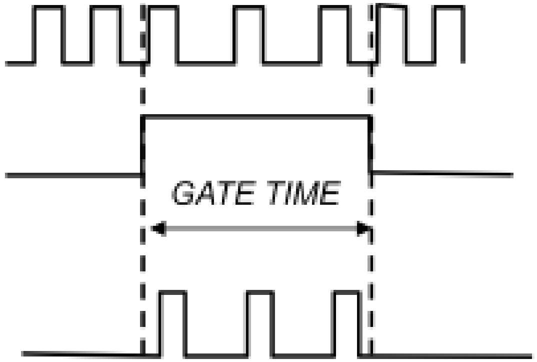




- The **rising edge** of the command signal enables the passage through the gate of the pulses to be counted
- The subsequent **falling edge** terminates the time interval during which the gate is enabled
- **AND** logic gate

Gate circuit





- The gate places **limits on the maximum frequency** at which the counter can be used
- In order not to cause counting errors when the signal has a frequency F, the switching times of the gate must be less than 1/(2F)

- **Response time** to Start and Stop commands as short as possible and equal for both commands

Counting circuits

- This block **counts the events** between the Start and Stop signals
- Binary counter → Simple structure → High speeds

- **Impulses counting**

- Initialization command to be sent to the counter → **Block reset**
- Limits on the frequency of the input signal

Control circuits

- They select the **mode and type** of the measurement:
  - Periodic, intermittent, continuous
  - Period, frequency, etc…
- They control the **opening and closing** of the gate
- They also control the **displaying** of the result and the **resetting** of the counter in the instrument
- They also enable the **transfer** of the obtained count to an auxiliary memory register to allow the display of the result

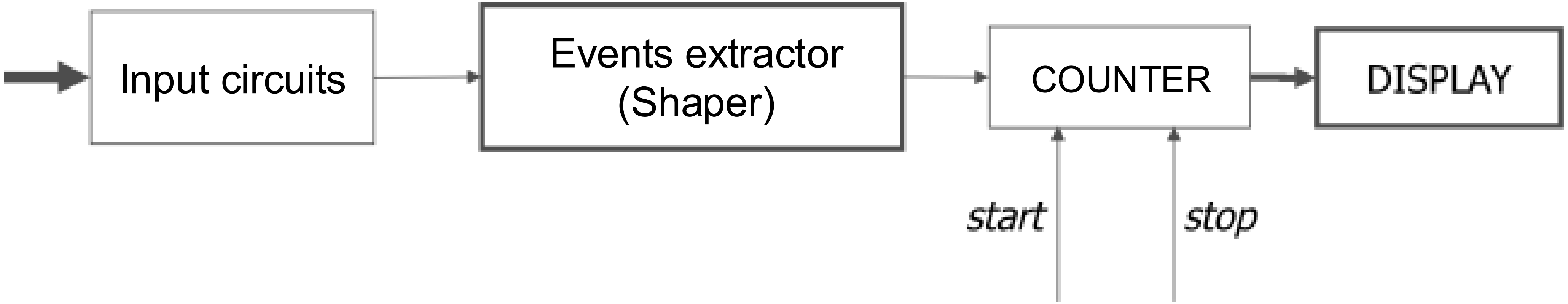
Visualization

- Devices for the **visual presentation** of the numerical result of the measurement:
  - LEDs
  - Liquid Crystal
  - 7-segment displays

- 3 to 8 decimal digits
- Resolution obtainable with a given instrument varies **according to the type of measurement** and the way in which the instrument itself is set up

Events counting

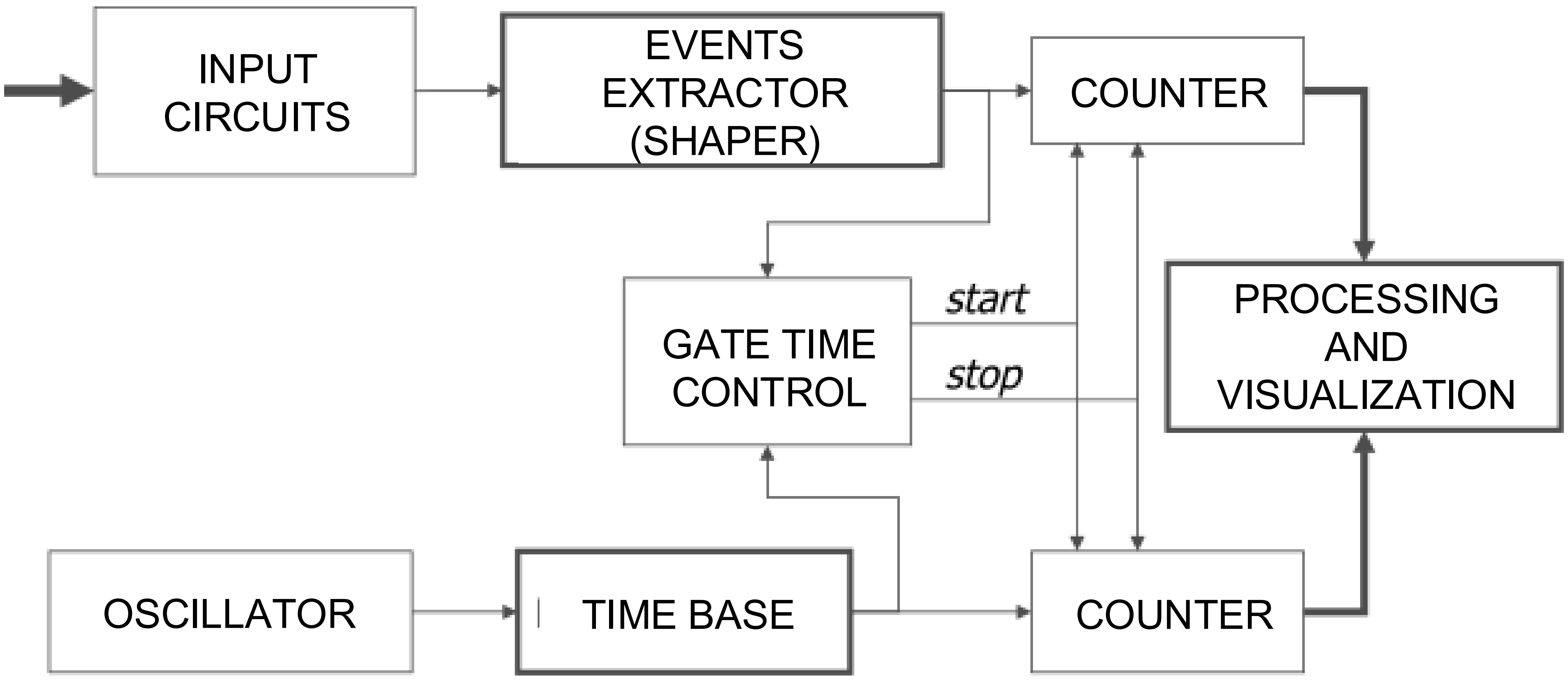
- The input signal is transformed into a **succession of pulses** to be sent to the counting block
- Signals of Start and Stop can be supplied either manually via the front panel of the instrument, or by means of **external signal generators**
- The output is a **number**



Reciprocal counting

- **Two distinct counters**:
  - One used to count the events associated with the **external signal**
  - One counting the pulses coming from **the internal time reference**
- The gates of the two counters are controlled in a coordinated manner by a single circuit:
  - **Same gate time** T_{ON}
- In this instrument, the operator, in addition to selecting the type of measurement desired, only sets the measurement time T_{ON}
  - The most suitable measurement mode is chosen by the instrument itself based on the characteristics of the input signal

Reciprocal counting



Reciprocal counting

- **Selection of the type of measurement**
- **Selection of the gate time** T_{ON}

- **Time counter** → Time base
- **Events counter** → Input signal

- If $F_X < F_R$ → Time meter
- If $F_X > F_R$ → Frequency meter

Measurement with internal time reference

- **Internal time reference** → Periodic signal of period T_R
- How many time units, of duration T_R, the unknown interval corresponds to
- Start and stop commands, determining the gate time are derived from the input signal

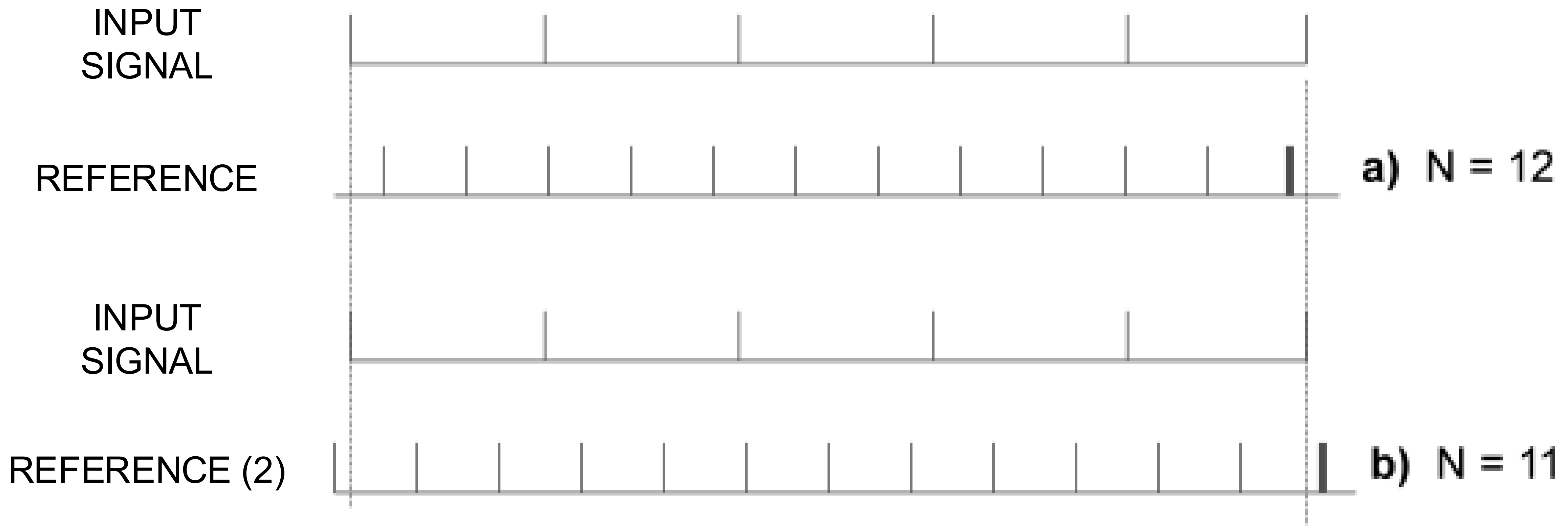
- Periodic signal → one event every period

- If start corresponds to one of these events and the Stop to the one immediately following → $T_{ON} = T_x$
- If the Stop is given at a distance of M periods → $T_{ON} = MT_x$

$$T_{ON} = MT_x = N_x \cdot T_R$$

Measurement with internal time reference

- Uncertainty in the counting equal to the resolution of the counter, equal to ±1 units of its least significant digit



Measurement with internal time reference

$$MT_x = (N_x \pm 1) \cdot T_R$$

$$T_x = \frac{N_x}{M} T_R \pm \frac{T_R}{M}$$

$$F_x = \frac{1}{T_x} = \frac{M}{N_x} F_R \pm \frac{M}{N_x^2} F_R$$

- As M increases, the resolution improves
- As M increases, the time required for the measurement also increases
- Resolution:

$$\frac{\Delta_x}{T_x} = \frac{T_R}{MT_x} = \frac{T_R}{T_{ON}} = \frac{1}{N_x}$$

Measurement with internal frequency reference

- F_x number of periods per time unit time interval
- The shaping circuit obtains an event at each period of the input signal and the instrument counts the number of events that occur in the known time interval T_{ON}
- $T_{ON} = K \cdot T_R = (N_x \pm 1)T_x$

$$F_x = \frac{N_x}{K} F_R \pm \frac{F_R}{K}$$

$$T_x = \frac{1}{F_x} = \frac{K}{N_x} T_R \pm \frac{K}{N_x^2} T_R$$

$$\Delta_F = \frac{F_R}{K} = \frac{1}{K T_R}$$

Study of the resolution

- Internal period reference vs internal frequency reference

- Time reference

$$\frac{\Delta_x}{T_x} = \frac{T_R}{MT_x} = \frac{T_R}{T_{ON}}$$

- Frequency reference

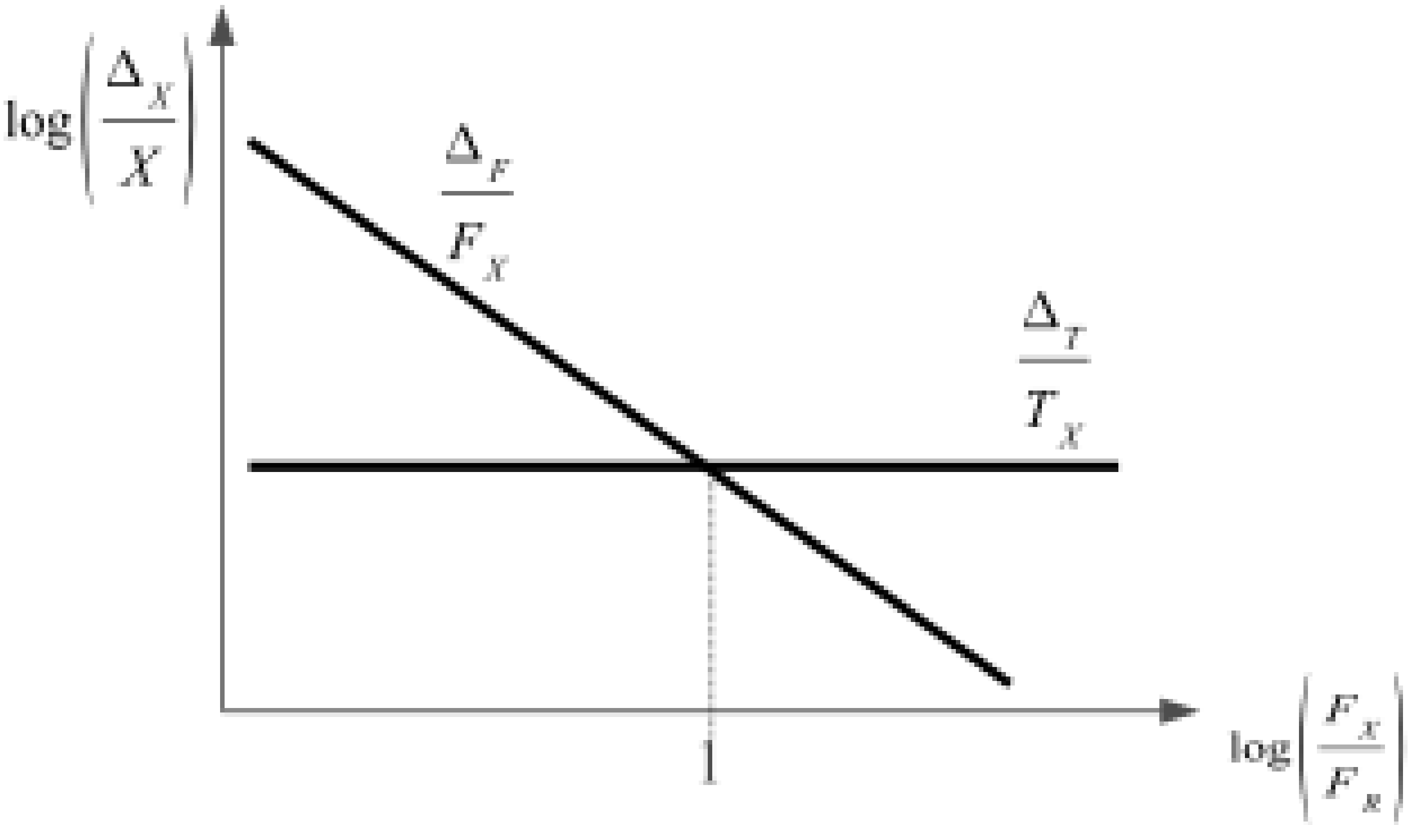
$$\frac{\Delta_F}{F_X} = \frac{F_R}{KF_X} = \frac{1}{F_x} \cdot \frac{1}{T_{ON}}$$

- Time reference: no dependance on F_x

Study of the resolution

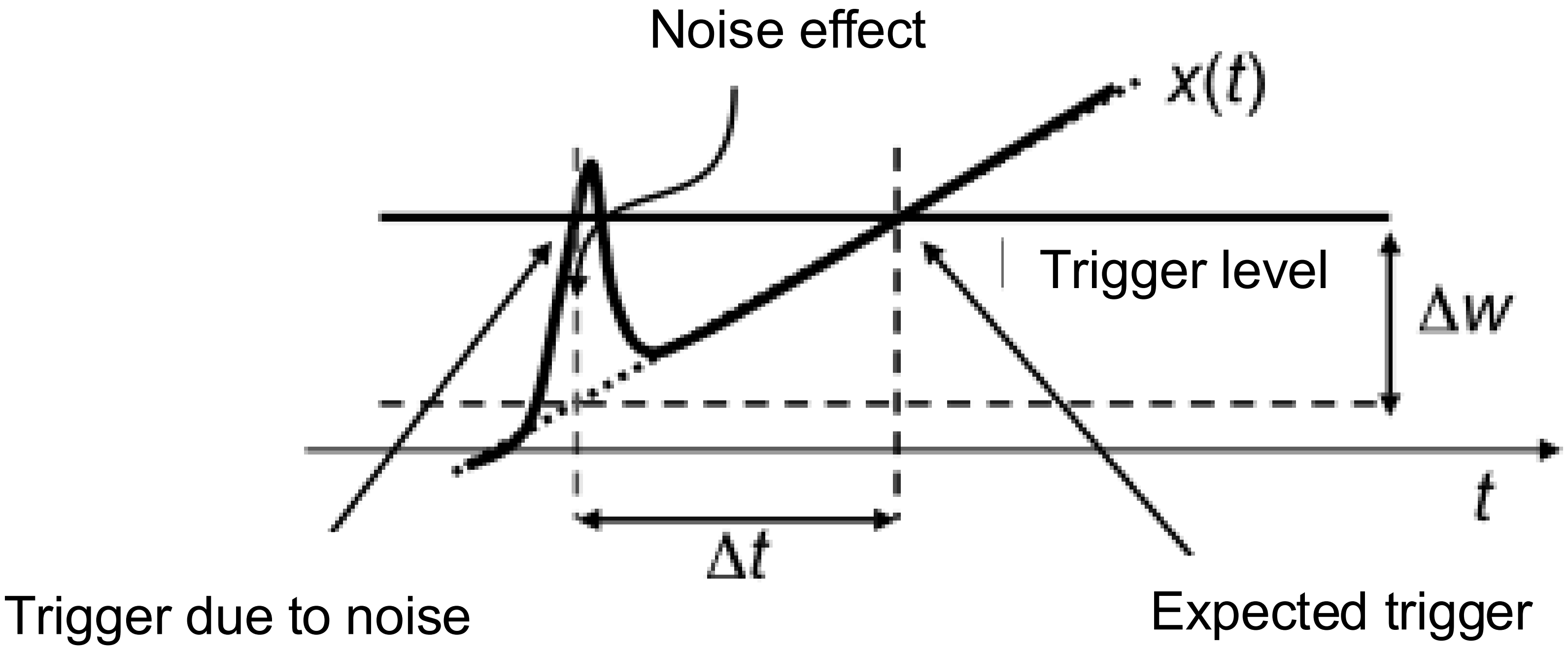
- Equal gate time

$$\frac{\Delta_x}{T_x} \leq \frac{\Delta_F}{F_X} \implies \frac{T_R}{T_{ON}} \leq \frac{1}{F_x} \cdot \frac{1}{T_{ON}} \implies F_x \leq F_S$$

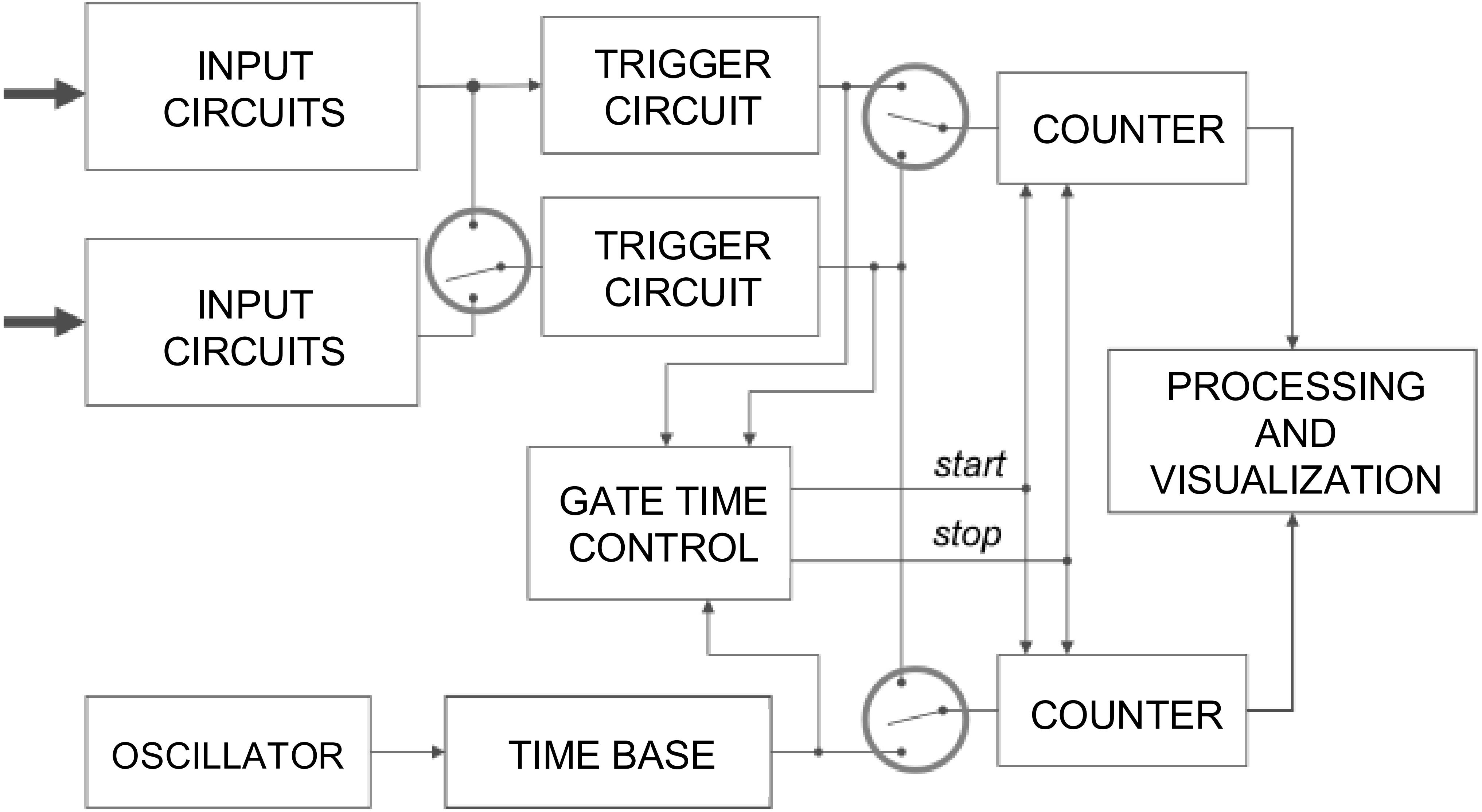


Sources of uncertainty

- **Resolution** (Start and Stop signals synchronization)
- **Time base stability**
  - Long use
  - Influence quantities
- **Trigger error**



Reciprocal counter with two input channels



Reciprocal counter with two input channels

- Measurement of the ratio of two frequencies
- Measurement of the duration of a time interval
- Measurement of the average duration of a time interval

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