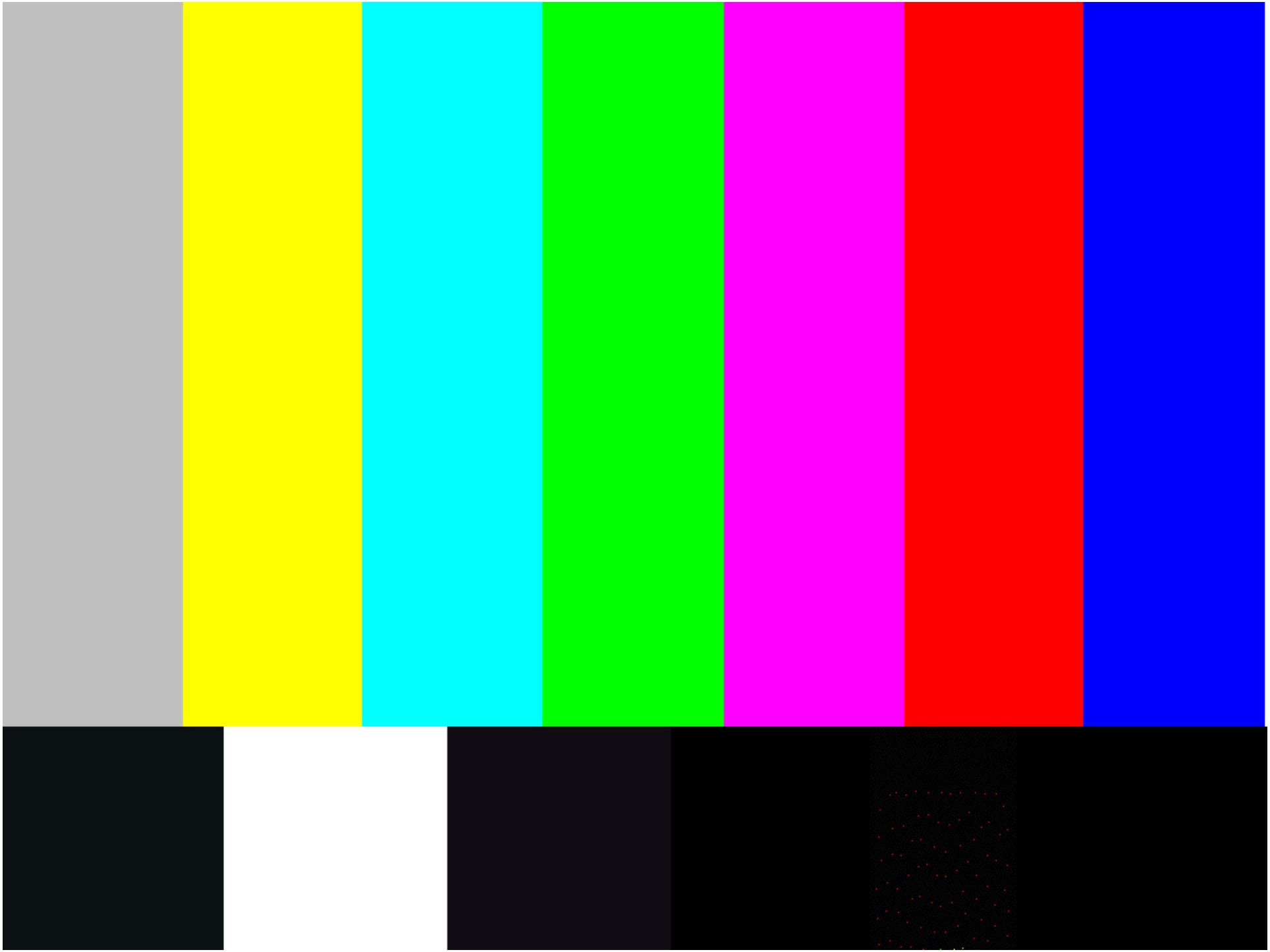


# Fundamentals of Time and Frequency

by:

Engr. Joseph Ronald Cañedo

# Introduction

- Time and frequency standards supply three basic types of information:
  1. time-of-day
     - Ø is provided in hours, minutes, and seconds, but often also includes the date (month, day, and year), e.g. Clock
  2. time interval
     - Ø is the duration or elapsed time between two events. The standard unit of time interval is the second(s).
  3. frequency
     - Ø is the rate of a repetitive event. If T is the period of a repetitive event, then the frequency f is its reciprocal, 1/T. The standard unit for frequency is the hertz (Hz).

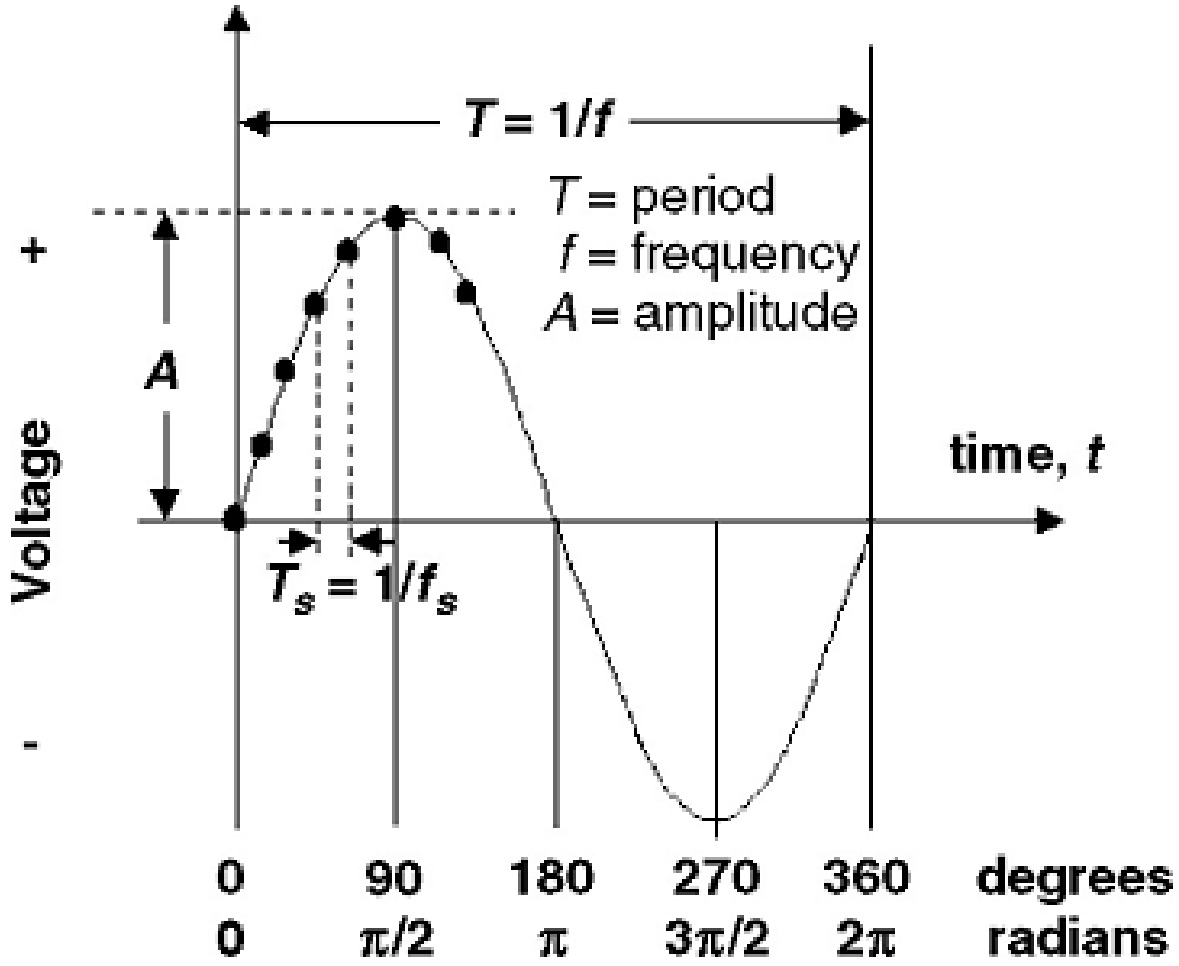
# Introduction

- Coordinated Universal Time (UTC)
  - Bureau International des Poids et Measures (BIPM) in Sevres, France
    - caters the collection of standard time gathered by the major metrology laboratories around the world.
      - National Institute of Standards and Technology (NIST)
    - generates two time scale
      - International Atomic Time (TAI) and Coordinated Universal Time (UTC)
        - » Both runs at the same frequency
        - » it differs by an integral number of seconds

# Time and Frequency Measurement

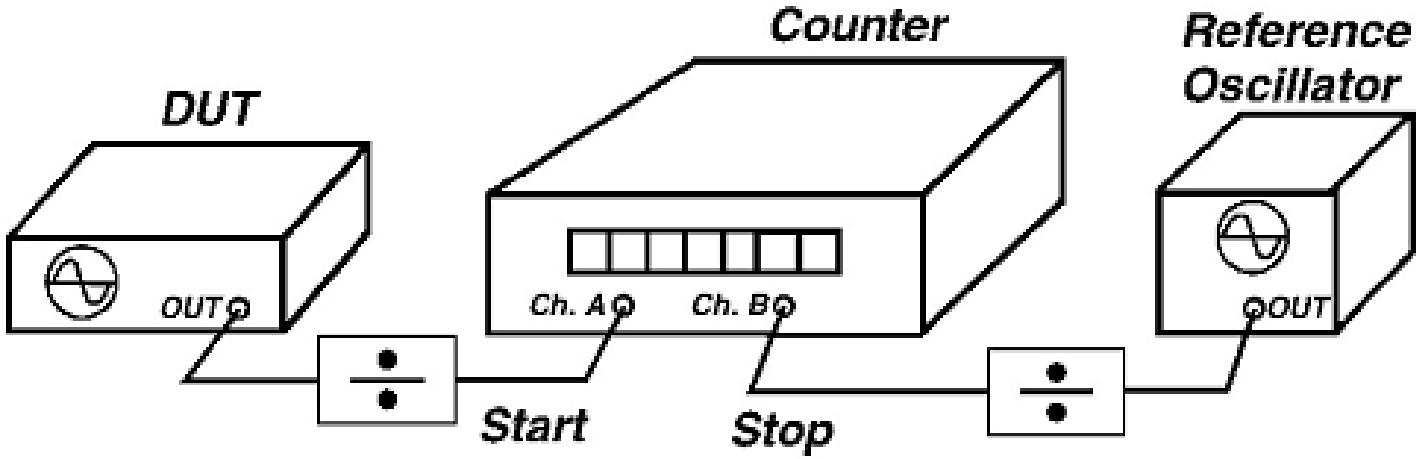
- Time and frequency measurements follow the conventions used in other areas of metrology.
  - The frequency standard or clock being measured is called the device under test (DUT). A measurement compares the DUT to a standard or reference.
  - The standard should outperform the DUT by a specified ratio, called the test uncertainty ratio (TUR). Ideally, the TUR should be 10:1 or higher. The higher the ratio, the less averaging is required to get valid measurement results.

# Time and Frequency Measurement



# Time and Frequency Measurement

## Accuracy




Measurement using a time interval counter.

# Time and Frequency Measurement

## Accuracy

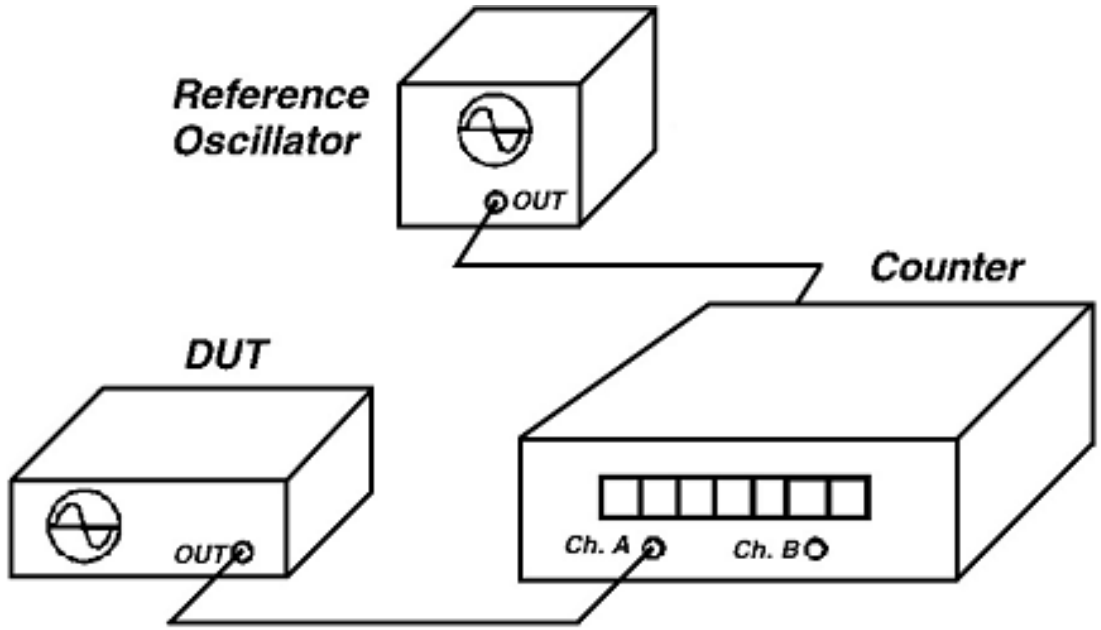
$$f(\text{offset}) = \frac{f_{\text{measured}} - f_{\text{nominal}}}{f_{\text{nominal}}}$$

where

- $f_{measured}$ is the reading from the frequency counter, and
- $f_{nominal}$ is the frequency labeled on the oscillator's nameplate, or specified output frequency.

# Time and Frequency Measurement

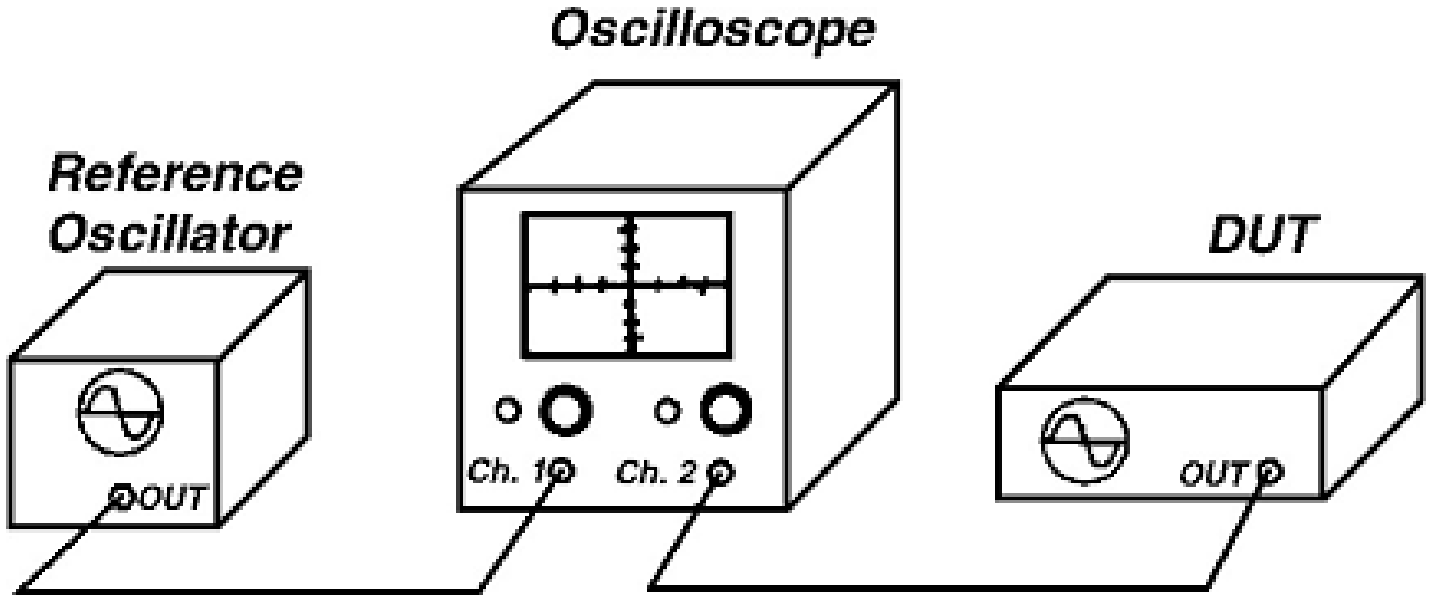
## Accuracy




Measurement using a frequency counter.

# Time and Frequency Measurement

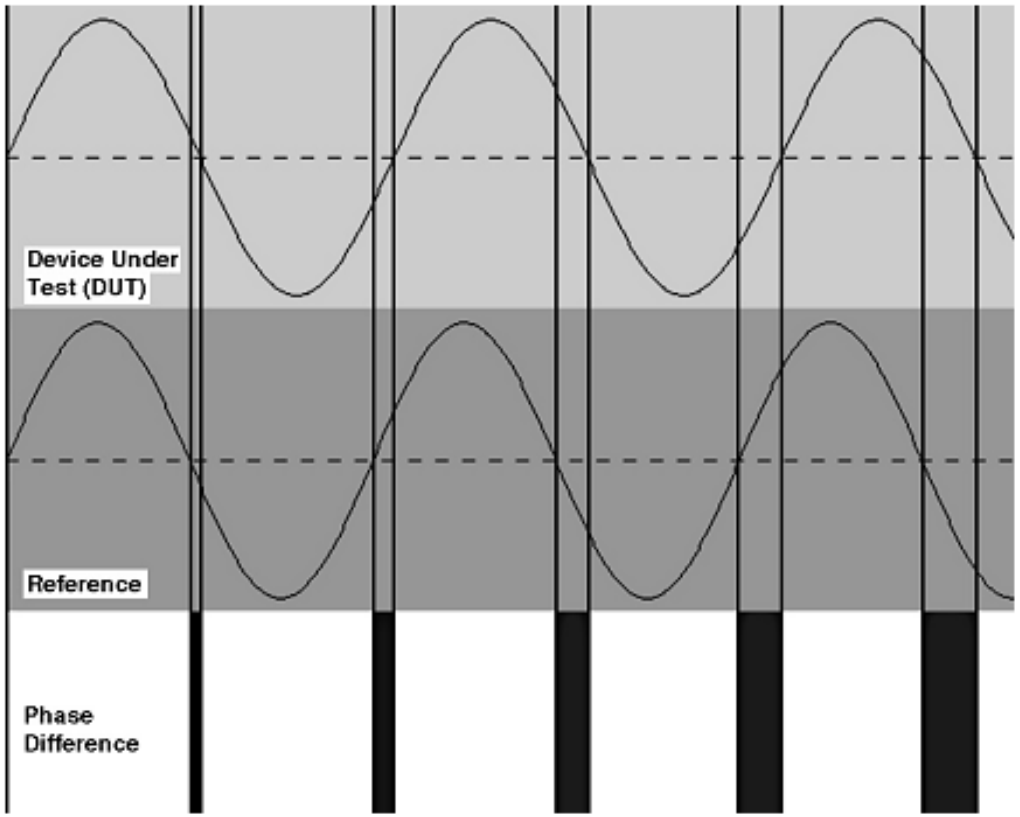
## Accuracy




Phase comparison using an oscilloscope.

# Time and Frequency Measurement

Accuracy



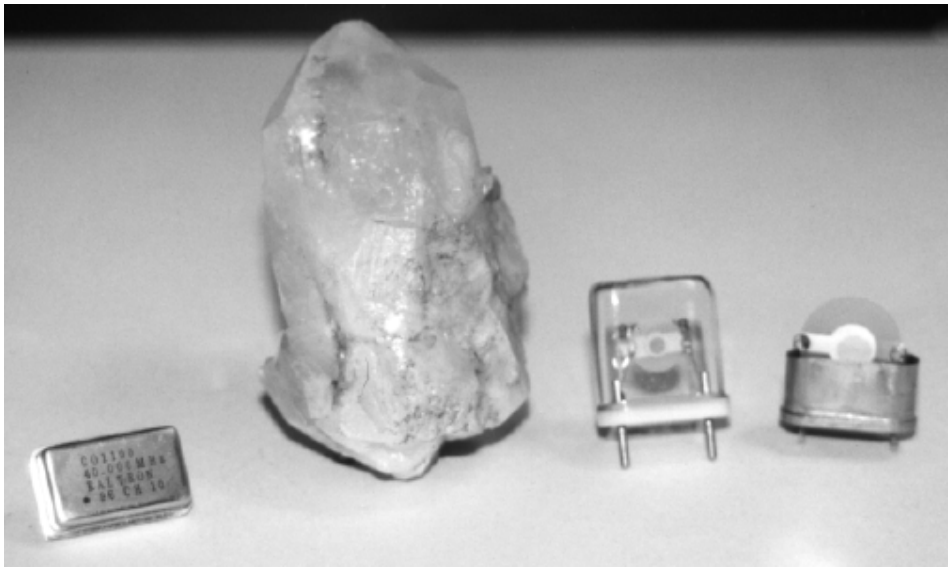

Two sine waves with a changing phase relationship.

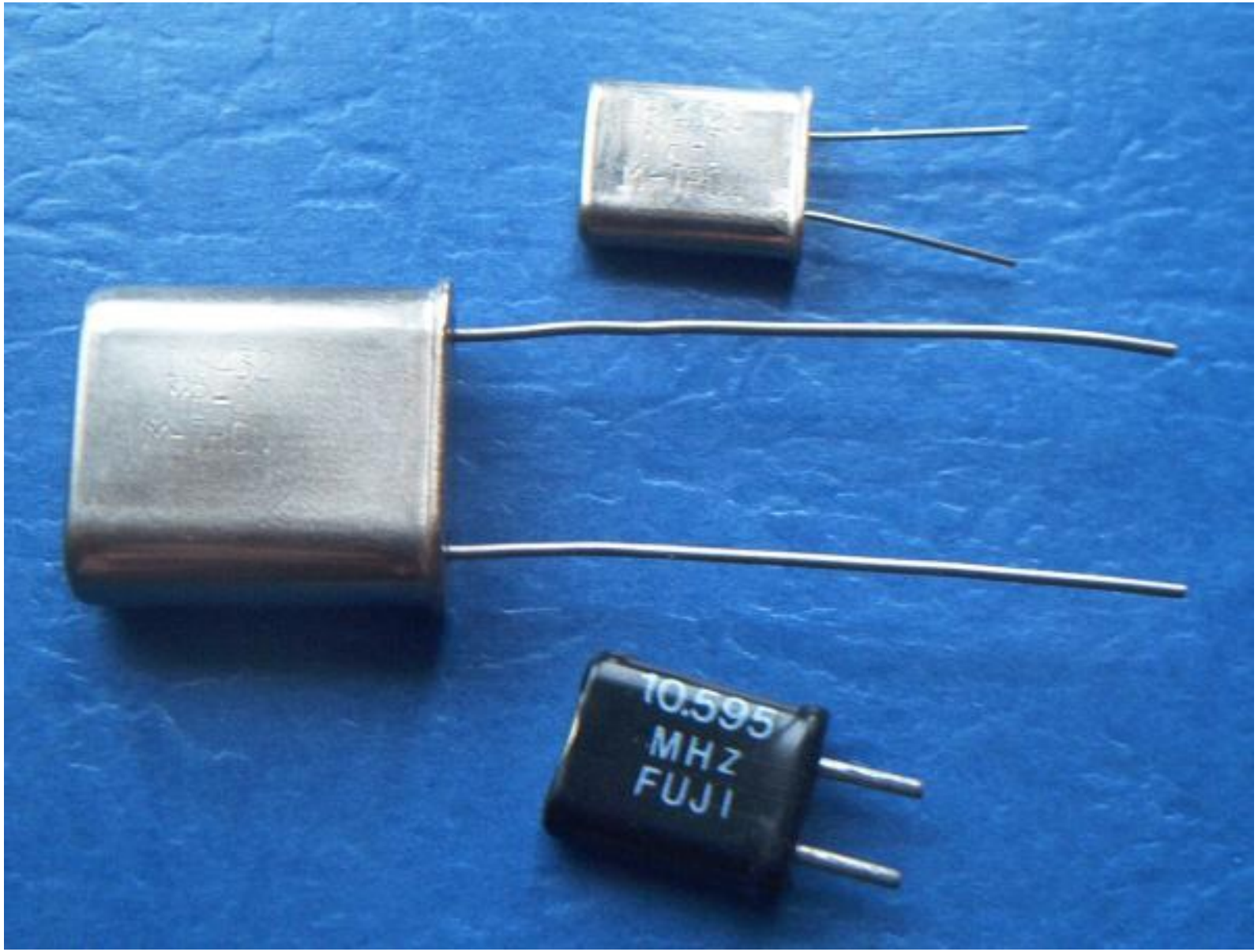
# Time and Frequency Standards

- All time and frequency standards are based on a periodic event that repeats at a constant rate. The device that produces this event is called a resonator - needs an energy source before it can move back and forth.
  - pendulum clock
- the energy source and resonator form an oscillator - runs at a rate called the resonance frequency.

# Time and Frequency Standards

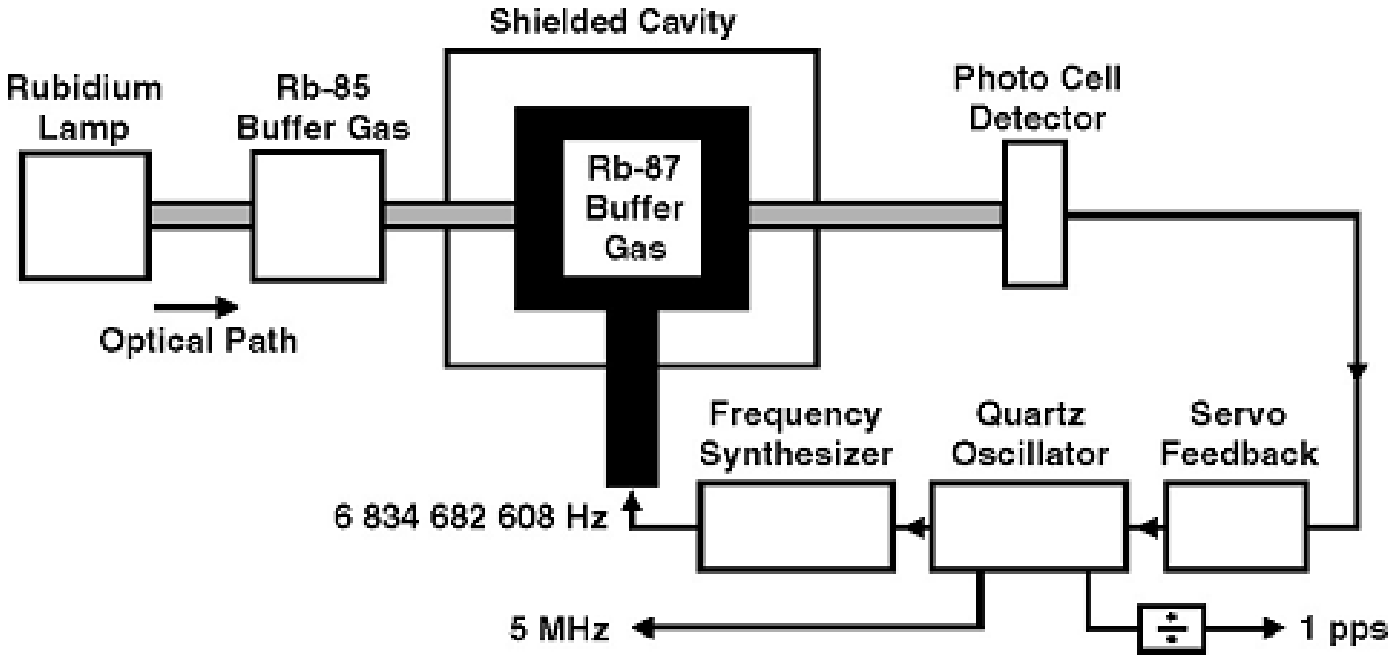
- Quartz Oscillators
  - Quartz crystal oscillators are by far the most common time and frequency standards. An estimated two billion ($2 \times 10^9$) quartz oscillators are manufactured annually.
    - wrist-watches, clocks, electronic circuits, and test and measurement equipment




10.595
MHz
FUJI

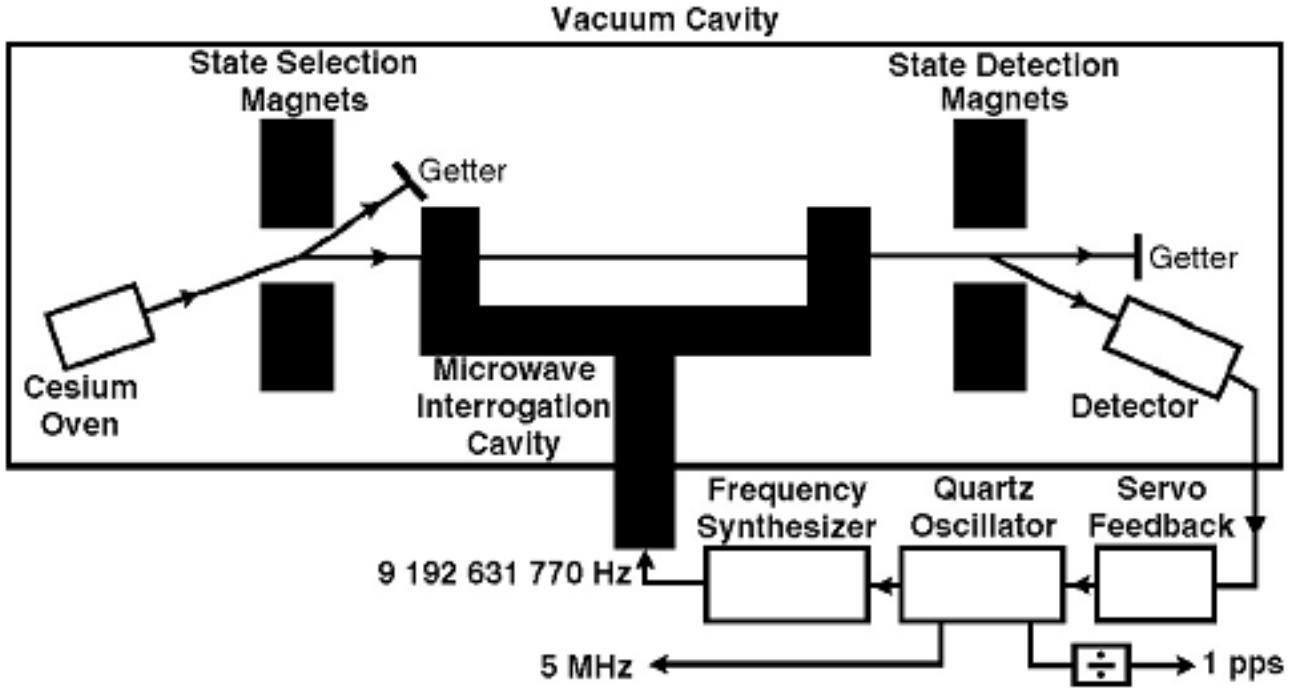
# Time and Frequency Standards

- Rubidium Oscillators
  - are the lowest priced members of the atomic oscillator family. They operate at 6,834,682,608 Hz, the resonance frequency of the rubidium atom ($^{87}$Rb), and use the rubidium frequency to control the frequency of a quartz oscillator.



# Time and Frequency Standards

- Cesium Oscillators
  - are primary frequency standards since the SI second is defined from the resonance frequency of the cesium atom ($^{133}$ Cs), which is 9,192,631,770 Hz. A properly working cesium oscillator should be close to its nominal frequency without adjustment, and there should be no change in frequency due to aging.

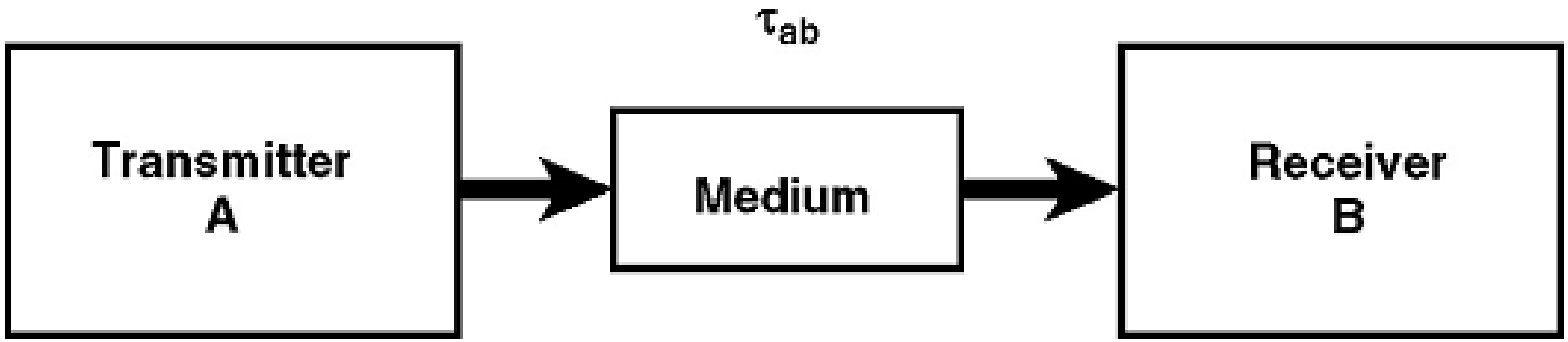


# Time and Frequency Transfer

- Many applications require clocks or oscillators at different locations to be set to the same time (*synchronization*), or the same frequency (*syntonization*).
- Time and frequency transfer techniques
  - are used to compare and adjust clocks and oscillators at different locations. Time and frequency transfer can be as simple as setting your wristwatch to an audio time signal, or as complex as controlling the frequency of oscillators in a network to parts in $10^{13}$.

# Time and Frequency Transfer

- Fundamentals of Time and Frequency Transfer




One-way time and frequency transfer.

# Time and Frequency Transfer

- Radio Time and Frequency Transfer Signals
  - HF Radio Signals (radio spectrum from 3 to 30 MHz)
  - LF Radio Signals (band from 30 to 300 kHz)
  - Global Positioning System (GPS) - consists of a constellation of at least 24 satellites that orbit the earth at a height of 20,200 km in six fixed planes inclined 55° from the equator.