How oscilloscopes work

By
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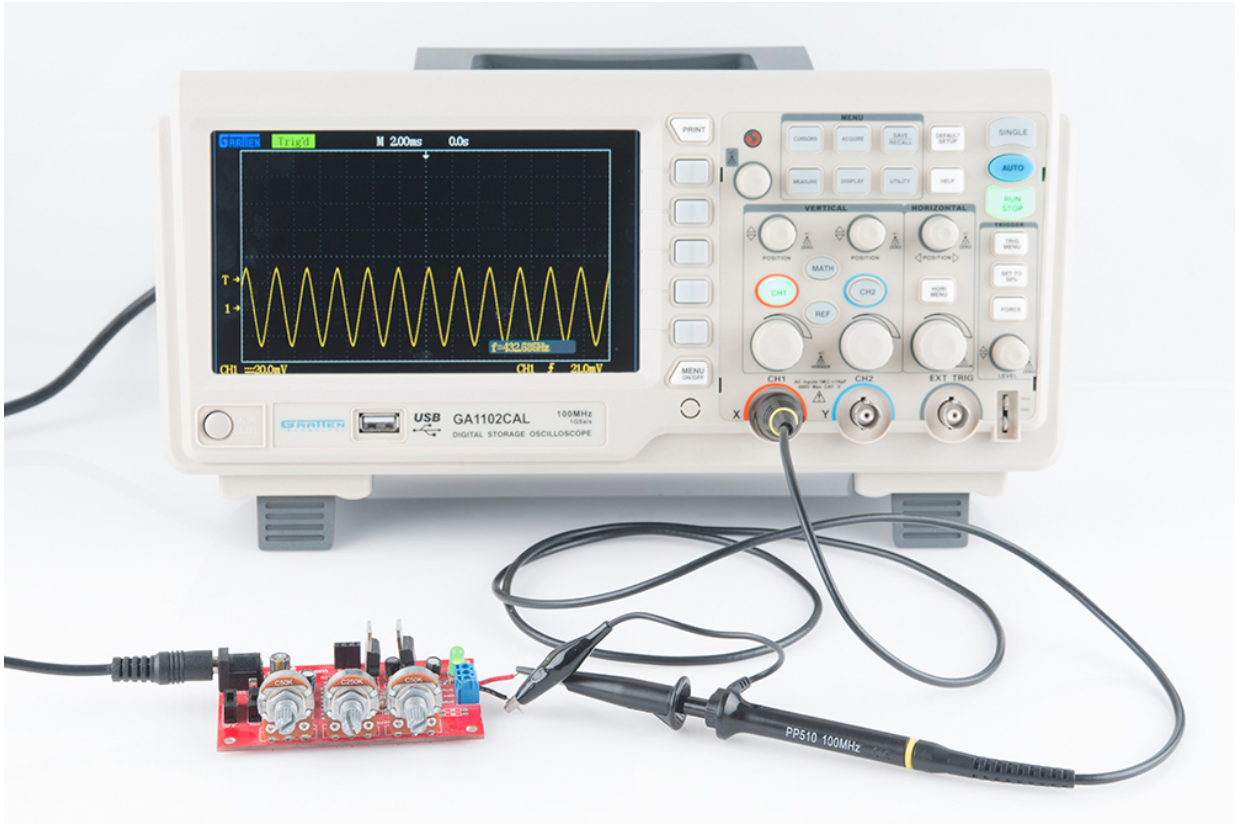
Introduction

- Who am I?
- Why this presentation

Why this presentation?

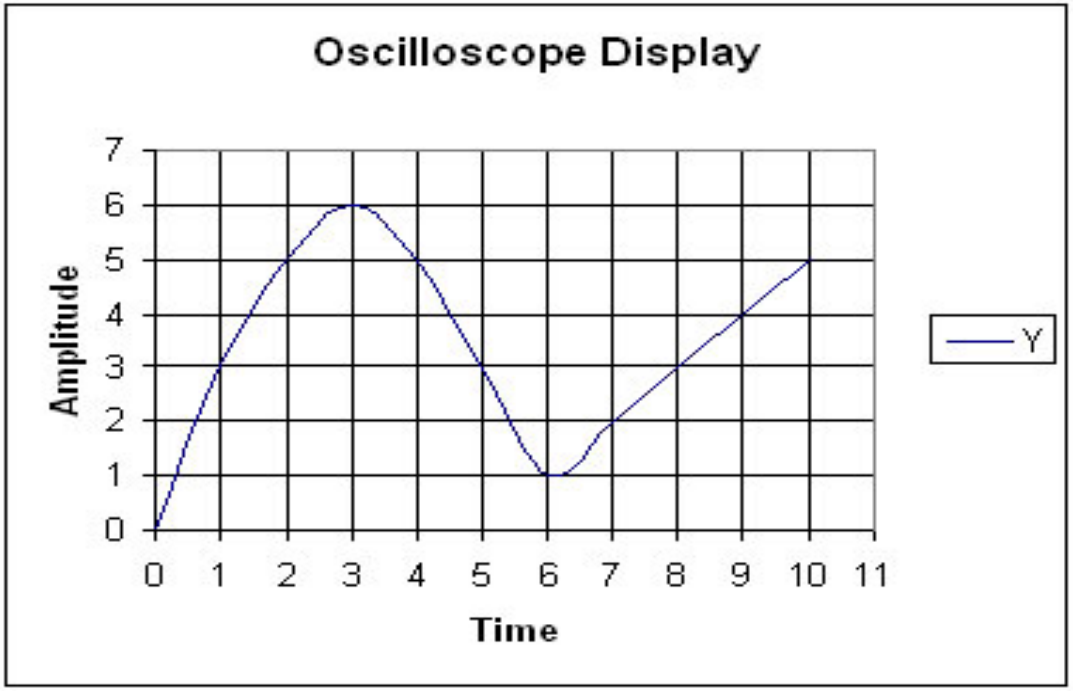
- Oscilloscopes are the most versatile tool to analyze electronic circuits
- They are not self-explaining



Schedule

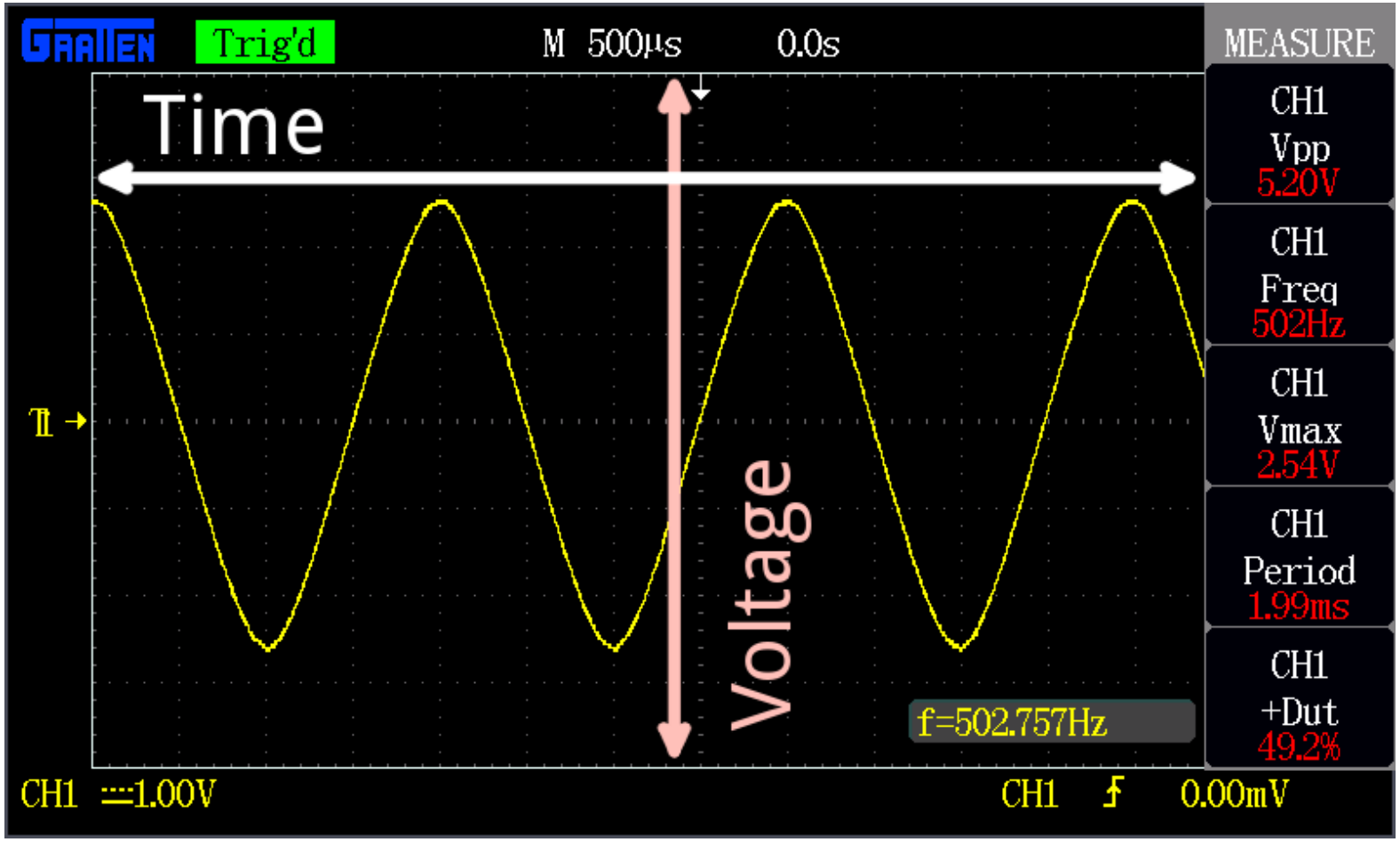
- Overview
- Display, Read the output
- Probes
- Input Stage
- Horizontal System
- Trigger System
- ADC Stage
- Measurements
- Accuracy
- Glimpse of more advanced features
- Q & A

Why use an oscilloscope

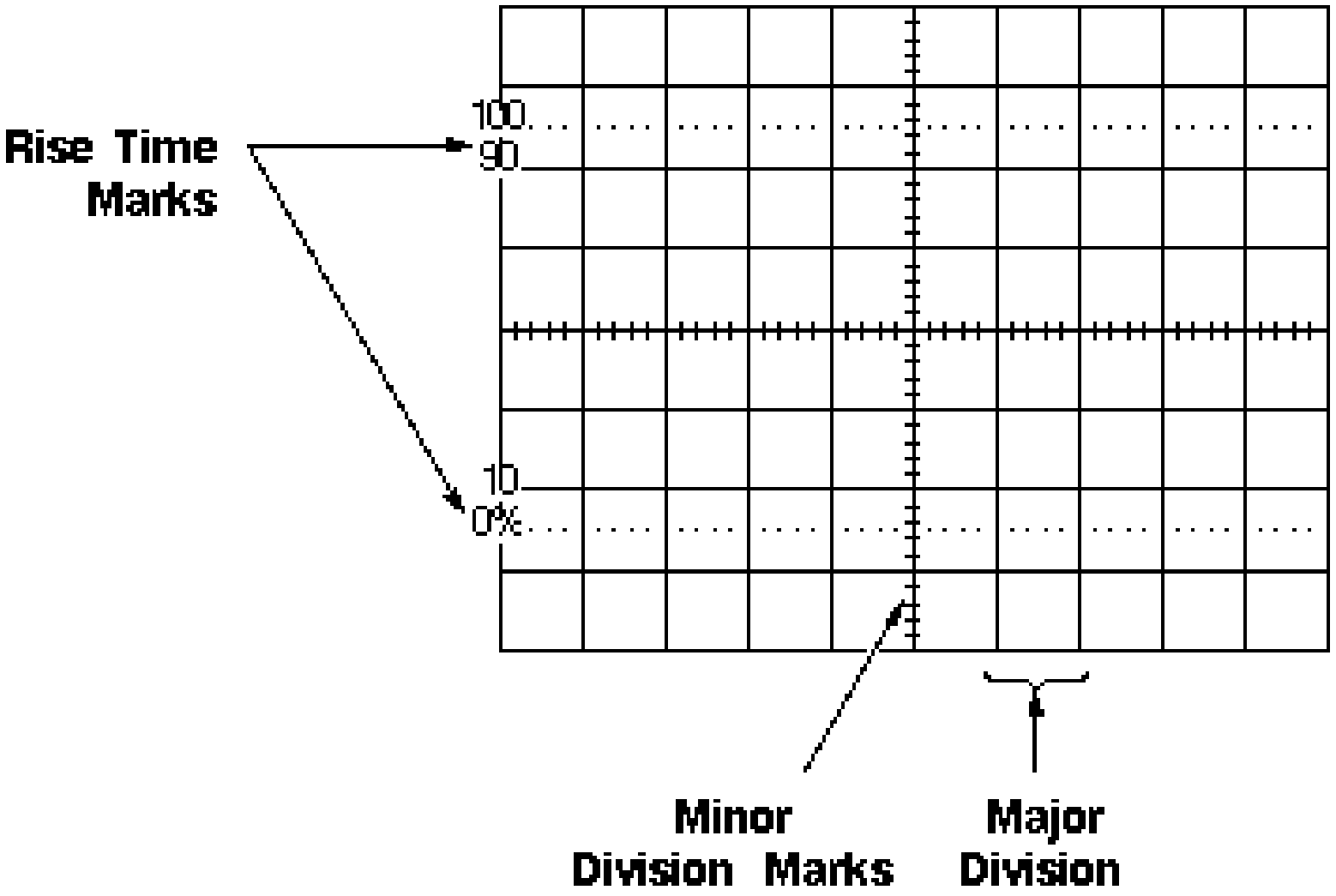


- You can determine the time and voltage values of a signal.
- You can calculate the frequency of an oscillating signal.
- You can see the "moving parts" of a circuit represented by the signal.
- You can tell if a malfunctioning component is distorting the signal.
- You can find out how much of a signal is direct current (DC) or alternating current (AC).

Display, read the output



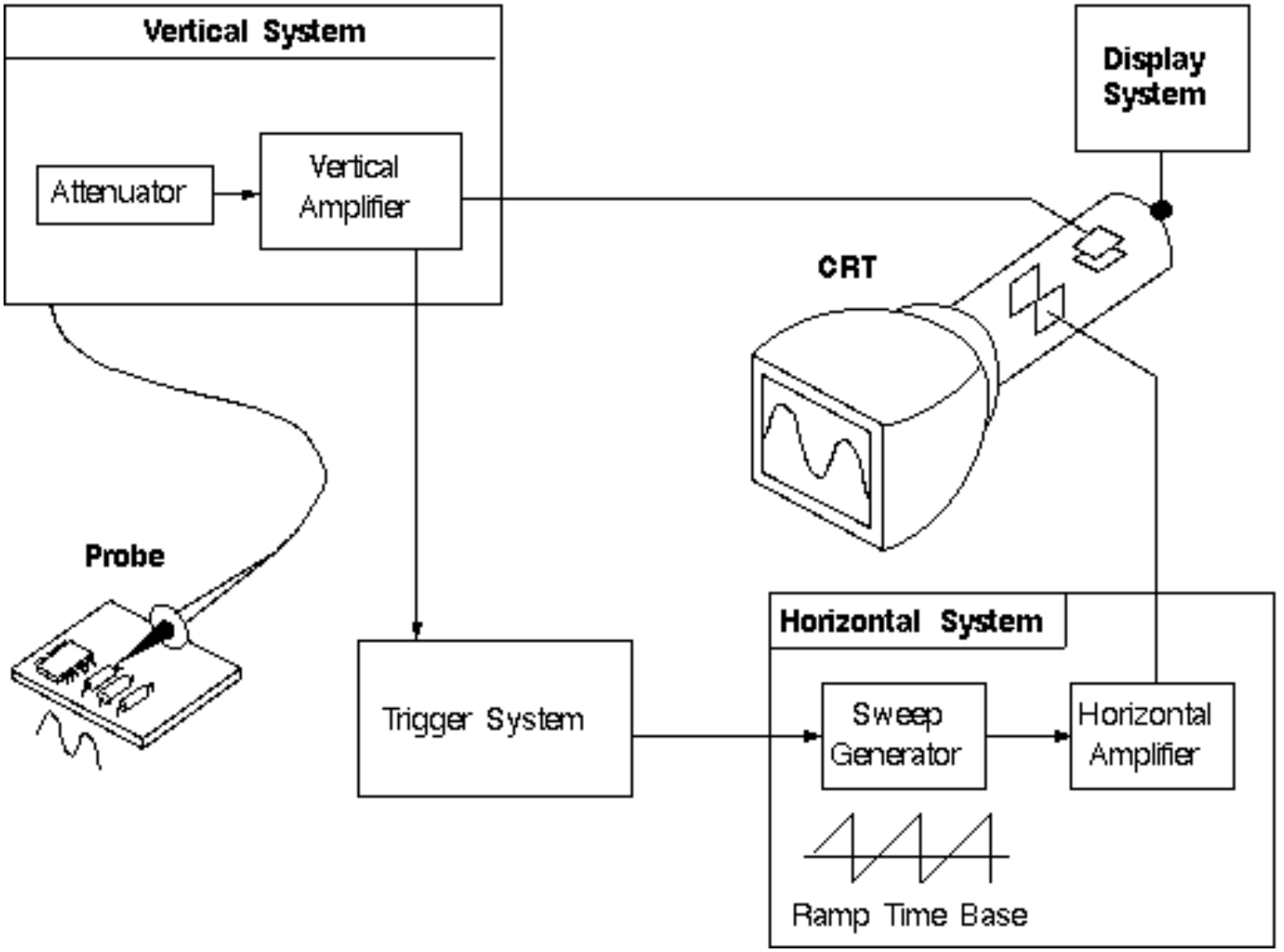
Display, read the output 2



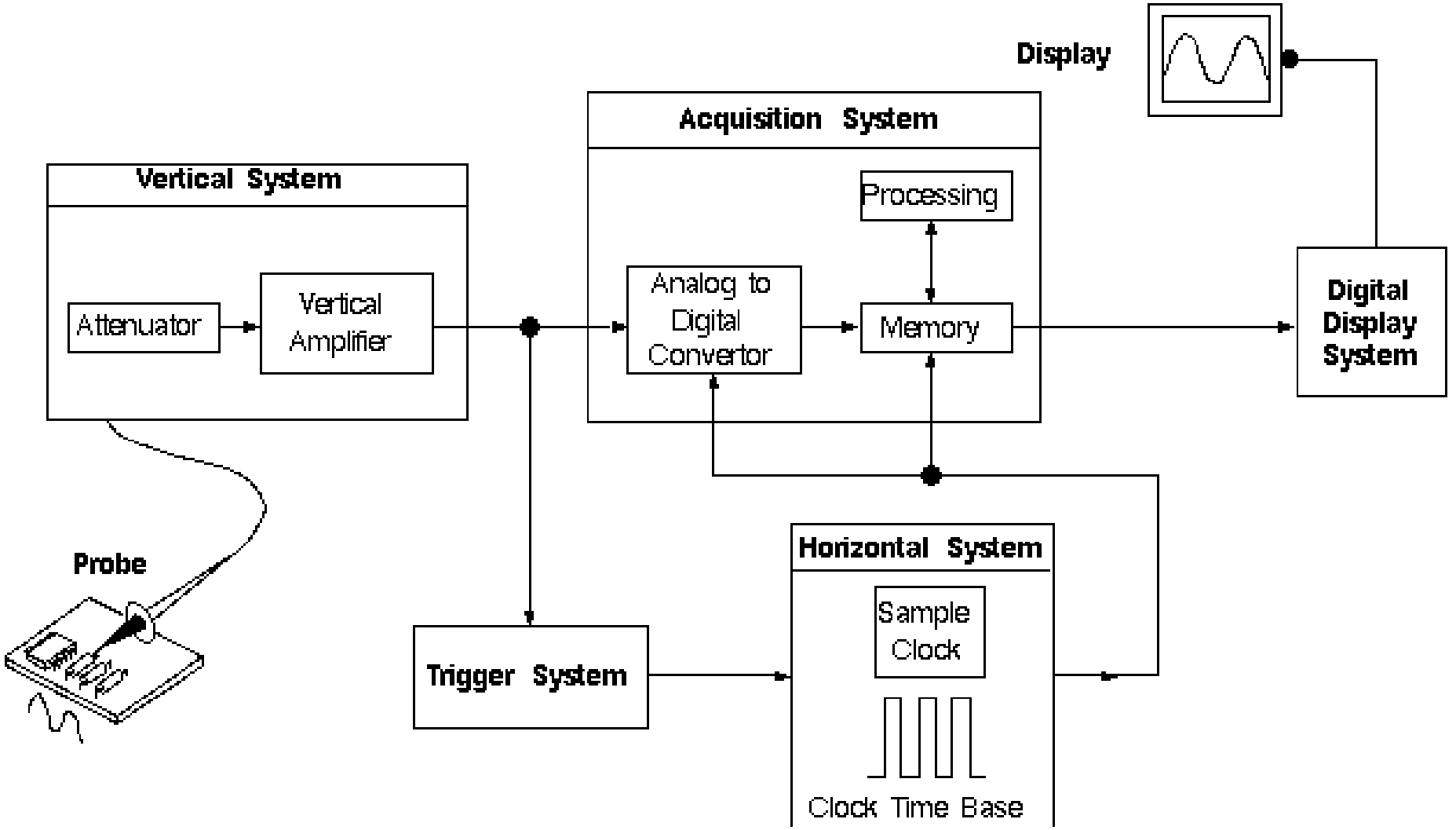
Why do have scopes so many buttons?

- Each of the different sub-systems in the block diagram has its own settings
- Each sub-system has its own section on the front panel
  - If you know how scopes work, you'll find the right button more easily
- More advanced scopes have more features so each sub-system has more buttons...

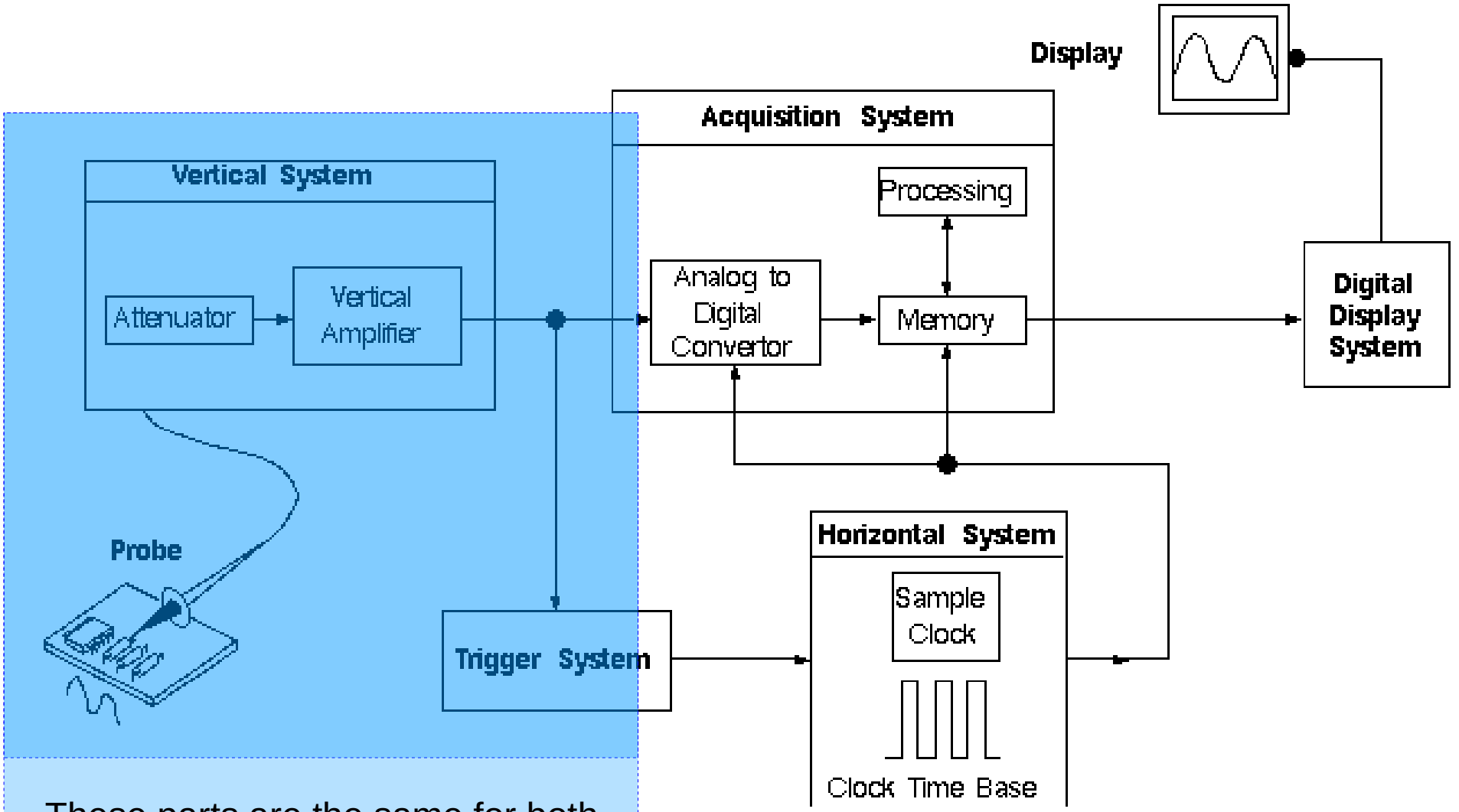
Blockdiagramm analog Scope



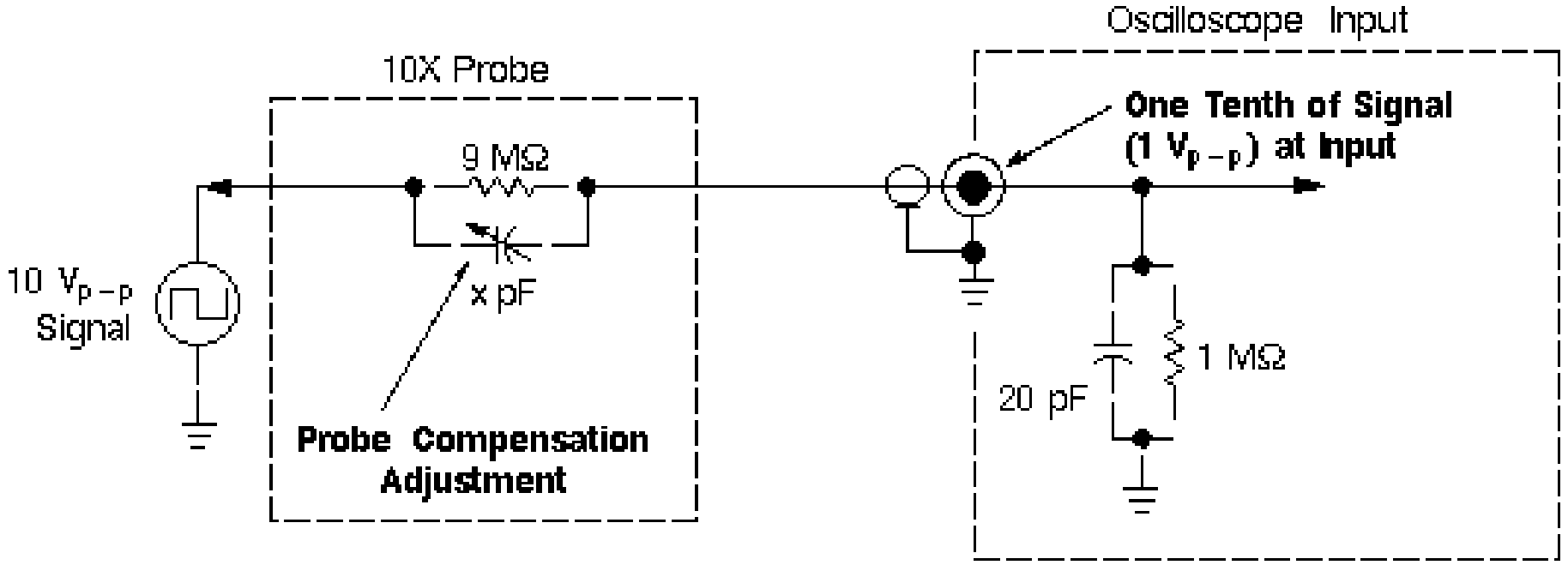
Blockdiagramm Digital Storage Oscilloscope (DSO)



Similarities between analog and DSO



Probes – not just wires

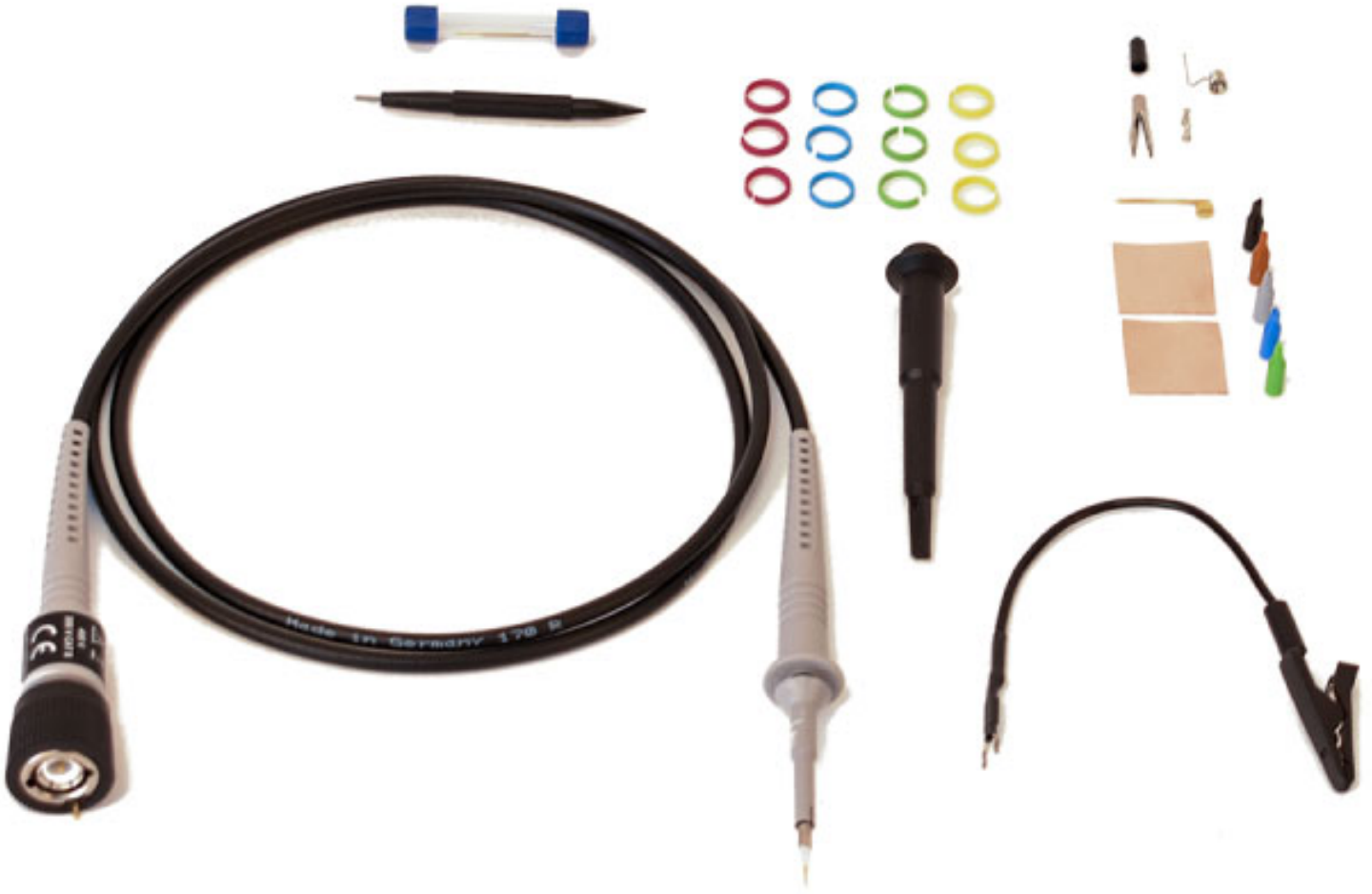


Schematic of a typical passive probe and the oscilloscope input

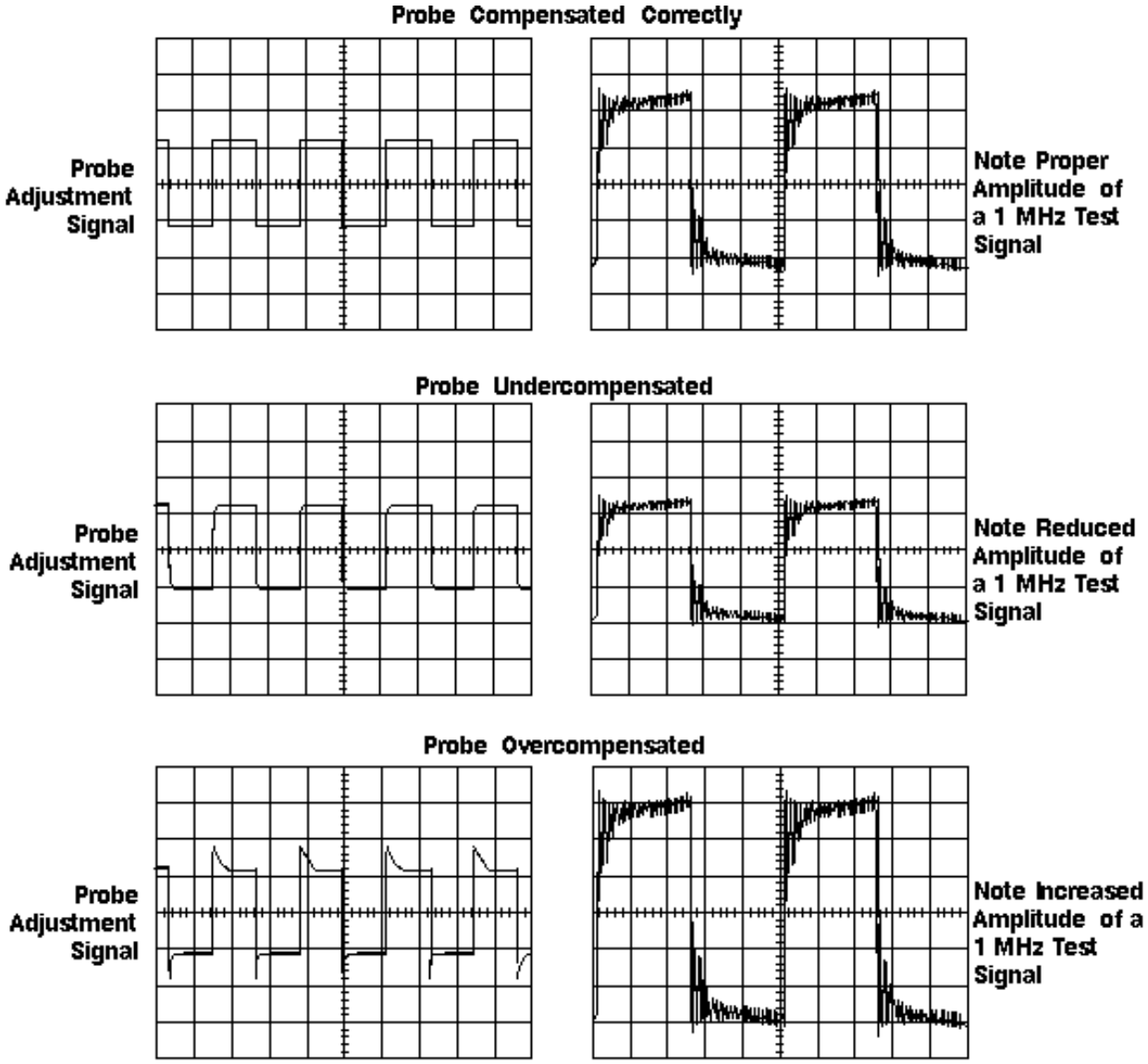
Probes 2

- Probe “ground” is connected to earth
  - Use differential probes for earth free operation
- Probes can influence your signal
  - Due to weak sources, high frequencies
- Tips:
  - Use hooks, holders etc. for hands-free operation
  - Use ground springs for reduced noise

Probe accessories



Probe compensation



Probe calibration: always use a plastic screwdriver!

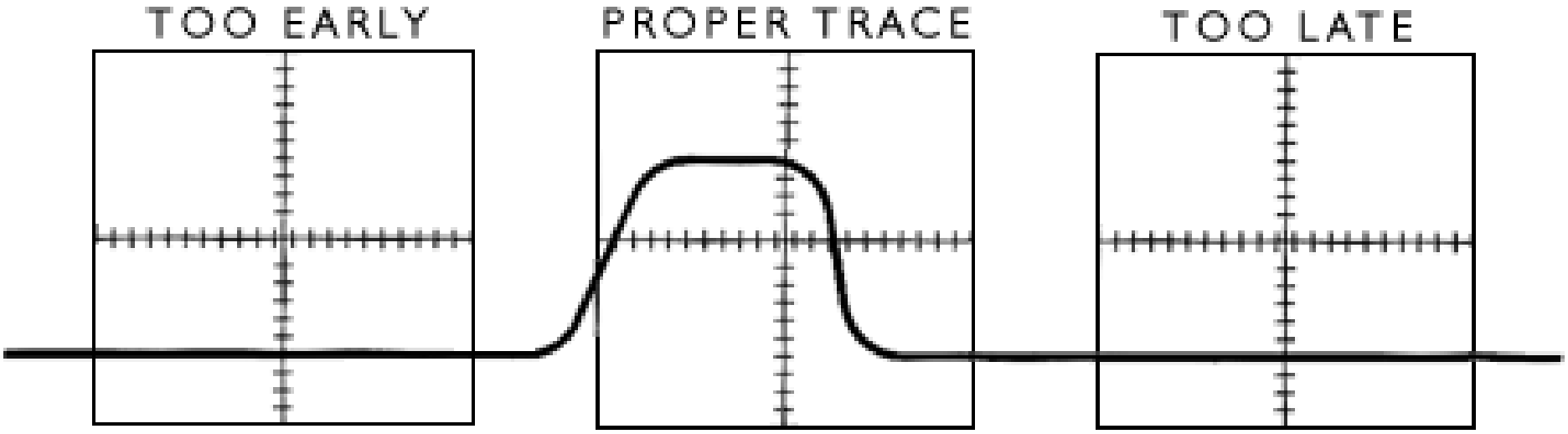
Vertical system (Input stage)

- Attenuation, scaling → Bigger/smaller
- Position → Moving up/down
- Coupling (DC, AC, GND) → What is shown
- More
  - Termination (1 MΩ, 50 Ω)
  - Bandwidth limit → Used for slower signals to reduce Noise

Horizontal System

- Adjust the time length you measure
  - Digital: Also adjusts the sampling rate
- Adjust the position you are interested in
  - Relative to the trigger event
- Digital: Allows you to „Zoom“ into a recorded signal
  - Sometimes zoom are separate buttons

Trigger System



The most important system to give you the measurement result you are looking for!

Trigger System 2

Trigger Types

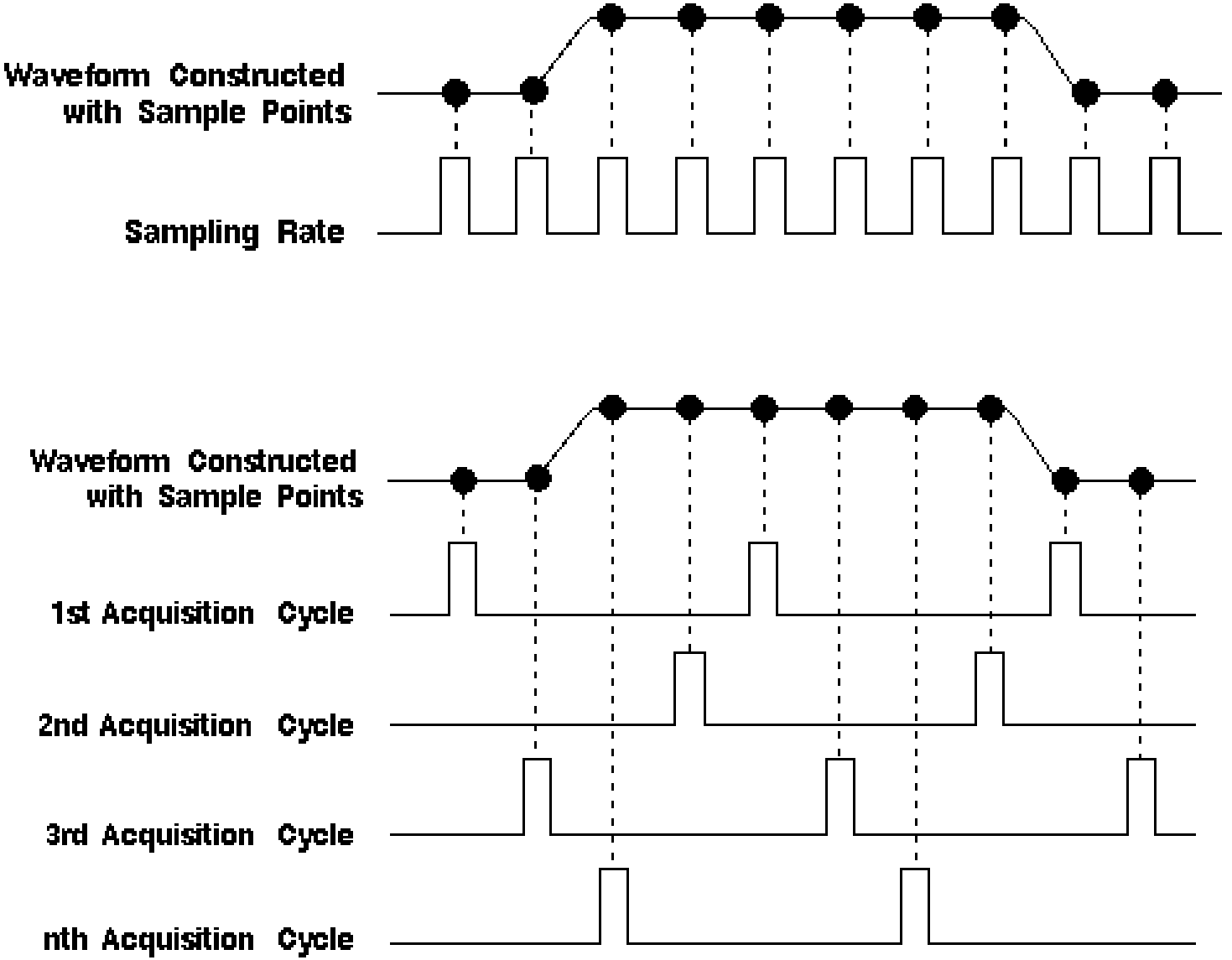
- Edge
  - Simple, most common
  - Rising, falling, both edges
- Pulse
  - Good for digital circuits, searching timing bugs
  - Longer/shorter than, between boundary

- Trigger Source
  - Input channels, external input, line (power input)
  - Coupling (DC, AC), Noise rejection (high-pass, low-pass)

Trigger System 3

- Trigger Modes
  - Normal
    - Refreshes the display on every trigger event
  - Single
    - Refreshes the display only once a trigger occurs
  - Auto
    - Refreshes the display periodically when no trigger occurs
- Hold off
    - Blocks the trigger system for a certain time before a new trigger event can happen.
    - Ex. block the trigger for one data frame duration

ADC Stage



Real-time Sampling

Equivalent-Time Sampling

ADC Stage 2

- Fast ADCs are expensive
- More channels means more ADCs
- Fast memory is expensive (recording time)
  - Fast four channel DSO with deep memory cost easy as much as a car
  - Good USB scopes are not much cheaper, because display and buttons are cheap

Measurements

- Analog (Manual):
  - Voltage
  - Time
  - Phase
- Digital (Automatic):
  - Voltage: Average, peak, RMS, min/max
  - Period, time, frequency: Average, min/max
  - Puls: Duration, puls-to-pause ratio, delay
  - Combination: Rise and fall time, overshot, phase

Accuracy

- Horizontal Accuracy (Time)
  - Digital: Only depending on the clock source (typ. Accurate to very accurate)
  - Analog: Depending on the clock source and linearity of the analog sweep generator (rather accurate)
- Vertical Accuracy (Amplitude)
  - Digital: Depending on the probe and input tolerance, input amplifier gain error, voltage reference error, ADC non-linearity, **ADC resolution (often only 8 bits!)**
  - Analog: Depending on the probe and input tolerance, input amplifier gain error

More advanced features

- Probes
  - Active probes, differential probes, optical receivers
- Trigger
  - Glitch, runt, dual channel, boolean operations
- Signal processing
  - Protocol decoders (sometimes incl. trigger), digital filters, math functions, FFT, statistics, pass/fail
- Other
  - Remote control, built-in documentation, post processing with Matlab/Python/C++, voice control

Q & A

- What kind of problems have you been confronted with?

- Images taken from:
  - http://uenics.evansville.edu/~amr63/equipment/scope/oscilloscope.html
  - http://www.pcbschematics.com/testing-equipment-osciliscope-analyzer/51-digital-testing-equipment-logic-time-analyzer.html
  - https://www.picotech.com/accessories/standard-passive-probes/p2036-passive-probe-300-mhz-bnc-single-pack
  - https://learn.sparkfun.com/tutorials/how-to-use-an-oscilloscope/all