The Architecture & Functionality of Low Cost Digital Storage Oscilloscopes

- by G4FDN

Background

- The club committee decided a few months ago that it would promote a commercial low cost Digital Storage Oscilloscope kit as this years club construction project.

Caveats: *I'm not an expert or professional on DSO's but was many years ago as a student I involved in a DSO design project. I also have a strong interest in microcontrollers and have constructed several projects using them.*

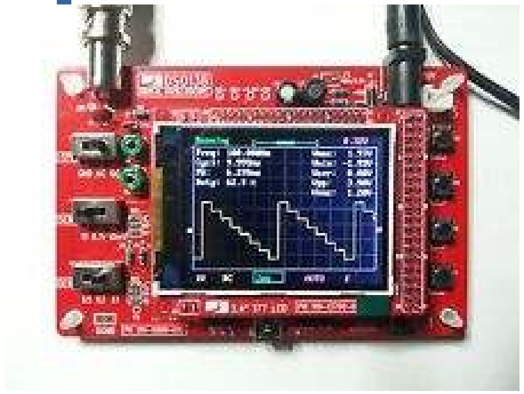
What I'm going to cover…

- The pros and cons of DSOs
- A quick review of general oscilloscope fundamentals
  - *What is an oscilloscope?*
  - *Oscilloscope probes*
  - *Voltage and timing measurements*
  - *Scaling waveforms on screen*
  - *Understanding triggering*
  - *Oscilloscope theory of operation & performance specs*
- Performance specifications
- The architecture of DSOs

Some Pros & Cons of DSOs

- Pros:
  - The ability to capture, store and replay waveforms
  - To transform captured waveforms into frequency domain via FFT
  - Other computation possible, e.g. averaging, multiple sample comparison
  - Better display, including colour
- Cons:
  - Quantisation distortion due to finite sampling
  - Other artefacts, e.g. aliasing

What is an Oscilloscope?



- **os·cil·lo·scope (ə-sĭl'ə-skōp**

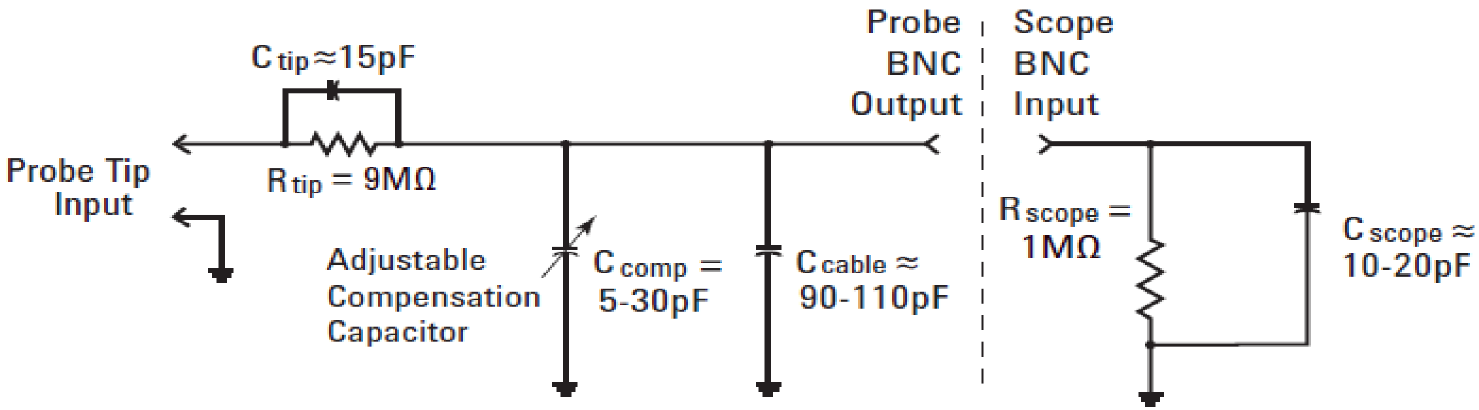
- Oscilloscopes convert electrical input signals into a visible trace on a screen - i.e. they convert electricity into light.
- Oscilloscopes dynamically graph time-varying electrical signals in two dimensions (typically voltage vs. time).
- Oscilloscopes are used by radio amateurs to test, verify, and debug electronic equipment and circuits.

Oscilloscope Probes

Probes are used to transfer the signal from the device-under-test to the oscilloscope's BNC inputs.

- There are many different kinds of probes used for different and special purposes (high frequency applications, high voltage applications, current, etc.).
- The most common type of probe used is called a Passive 10:1 Voltage Divider Probe.

Passive 10:1 Voltage Divider Probe High-frequency/DC Model

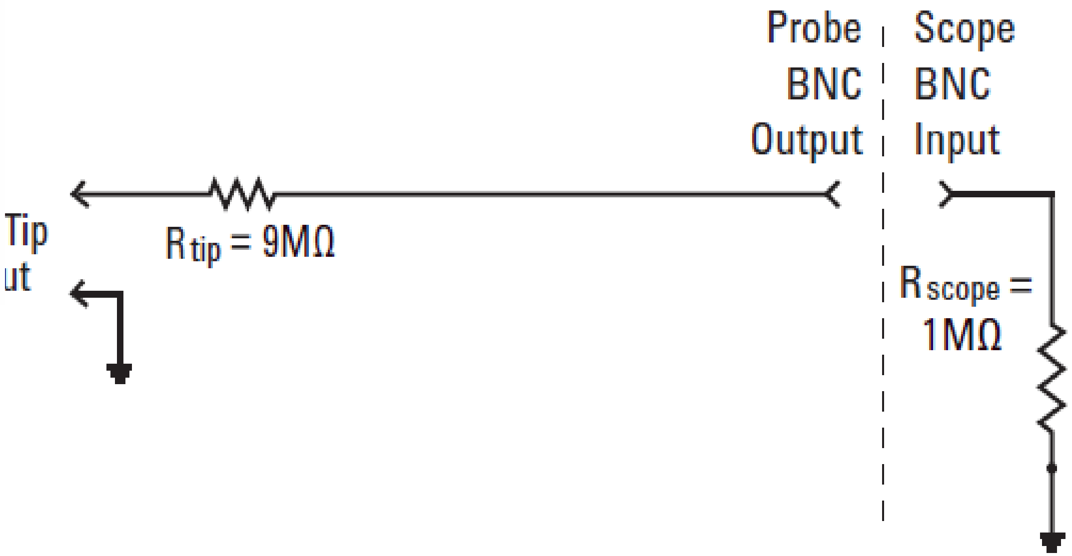


- <u>Passive:</u> Includes no active elements such as transistors or amplifiers.
- <u>10-to-1:</u> Reduces the amplitude of the signal delivered to the scope's BNC input by a factor of 10. Also increases input impedance by 10X.

Note: All measurements must be performed relative to ground!

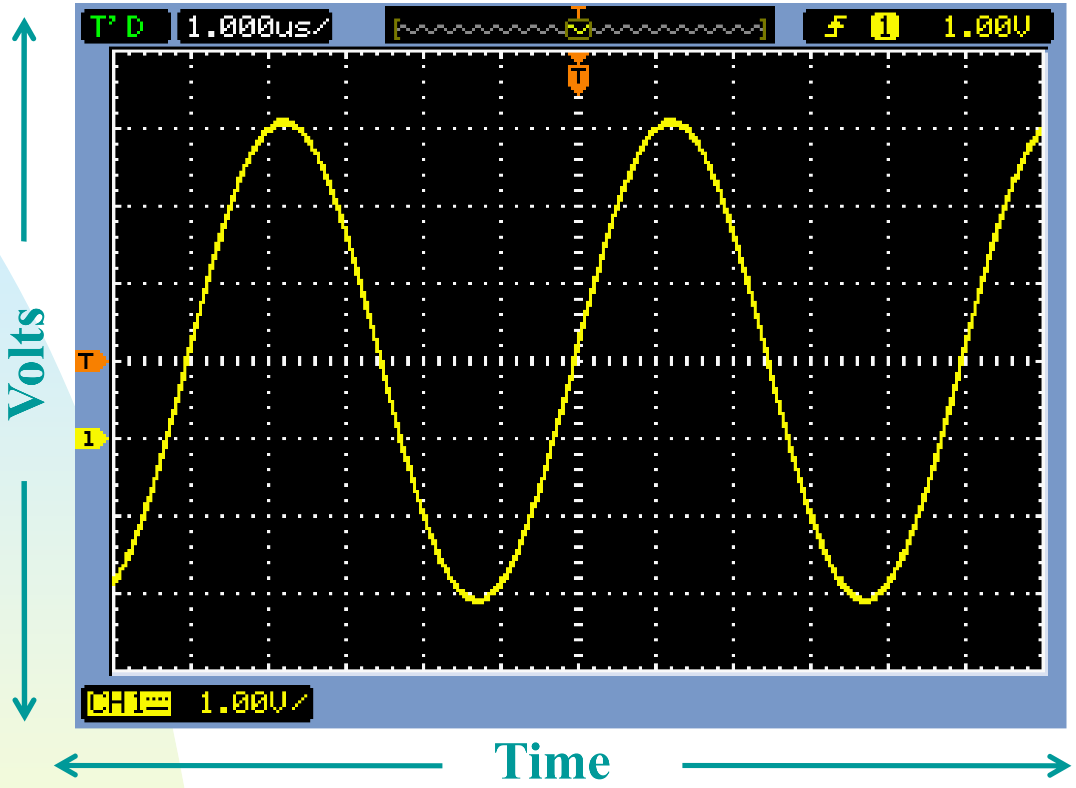
Most DSO kits come with 1:1 probes

Low-frequency/DC Model



- <u>Low-frequency/DC Model:</u> Simplifies to a 9-MΩ resistor in series with the scope's 1-MΩ input termination.
- <u>Probe Attenuation Factor:</u>

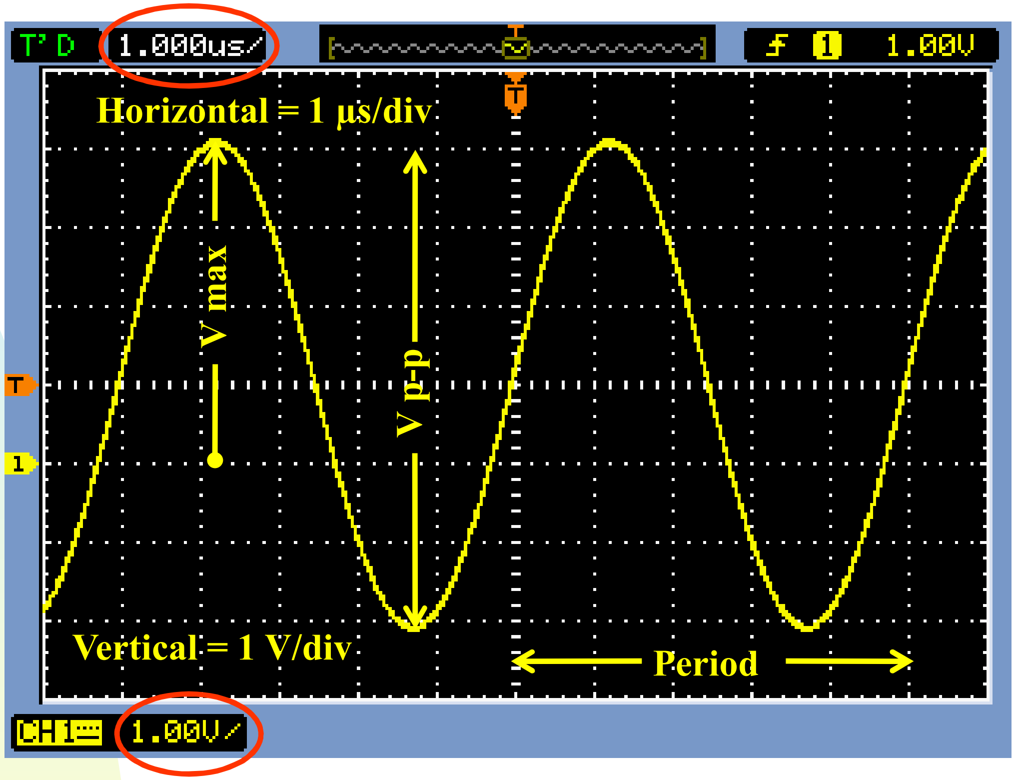
Understanding the Scope's Display



- Waveform display area shown with grid lines (or divisions).
- Vertical spacing of grid lines relative to Volts/division setting.
- Horizontal spacing of grid lines relative to sec/division setting.

Making Measurements – by visual estimation

The most common measurement technique



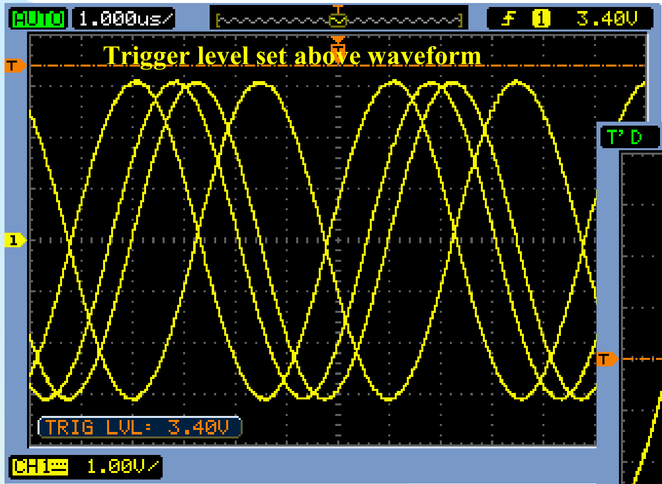
- Period (T) = 5 divisions x 1 µs/div = 5 µs, Freq = 1/T = 200 kHz.
- V p-p = 6 divisions x 1 V/div = 6 V p-p

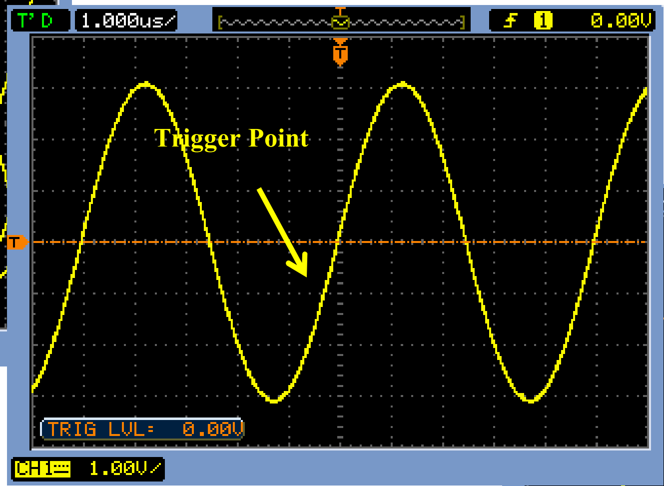
Understanding Oscilloscope Triggering

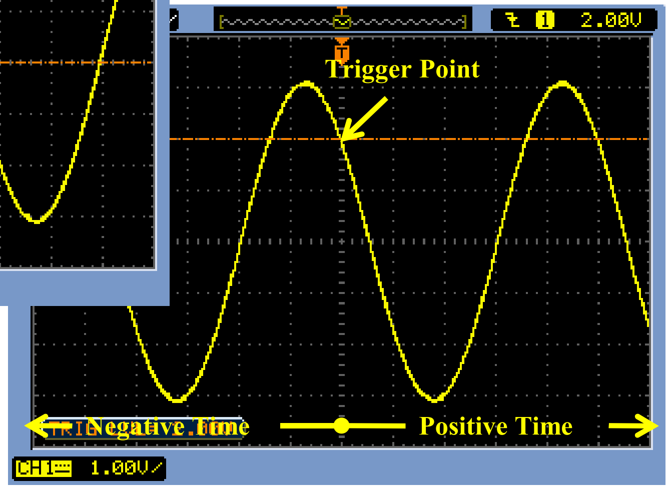
Triggering is often the least understood function of a scope, but is one of the most important capabilities that you should understand.

- Think of oscilloscope “triggering” as “synchronized picture taking”.
- One waveform “picture” consists of many consecutive digitized samples.
- “Picture Taking” must be synchronized to a unique point on the waveform that repeats.
- Most common oscilloscope triggering is based on synchronizing acquisitions (picture taking) on a rising or falling edge of a signal at a specific voltage level.

Triggering Examples







Untriggered
(unsynchronized picture taking)

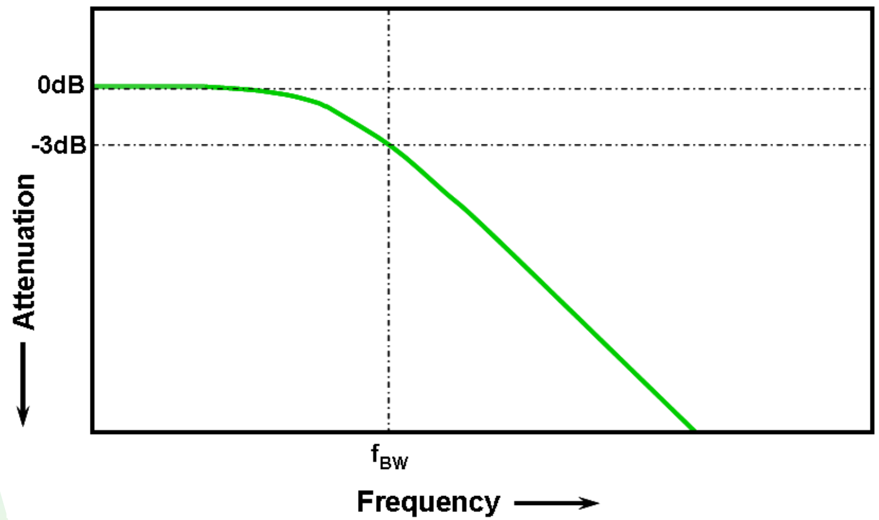
Trigger = Rising edge @ 0.0 V

Trigger = Falling edge @ +2.0 V

- **Default trigger location (time zero) on DSOs = center-screen (horizontally)**

Oscilloscope Performance Specifications

"Bandwidth" is the most important oscilloscope specification

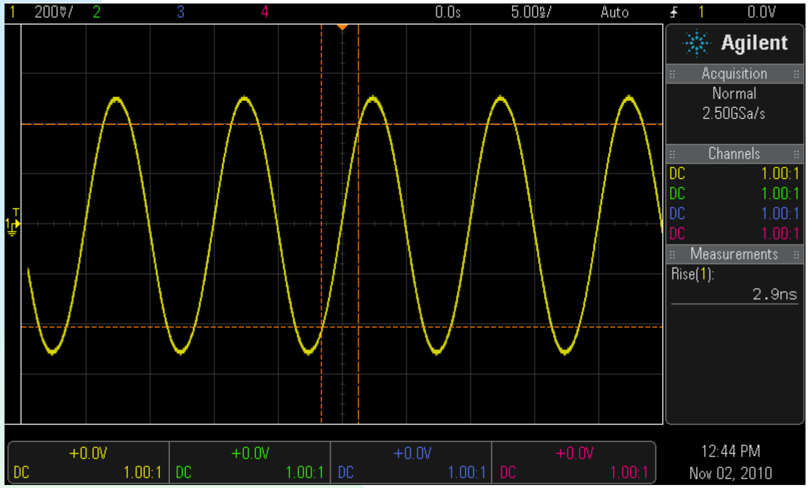


Oscilloscope Frequency Response

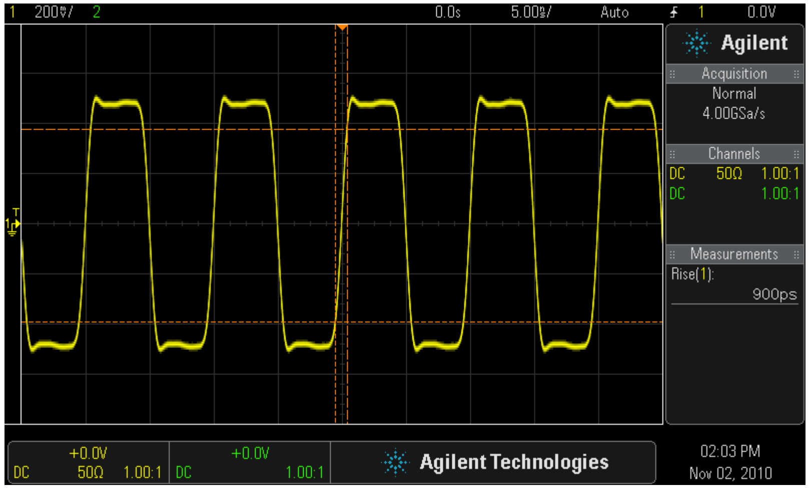
- All oscilloscopes exhibit a low-pass frequency response.
- The frequency where an input sine wave is attenuated by 3 dB defines the scope's bandwidth.
- -3 dB equates to ~ -30% amplitude error (-3 dB = 20 Log $\frac{Vo}{Vi}$).

Selecting the Right Bandwidth

Input = 1MHz Digital Clock Signal



Response using a 1-MHz BW scope



Response using a 5 MHz BW scope

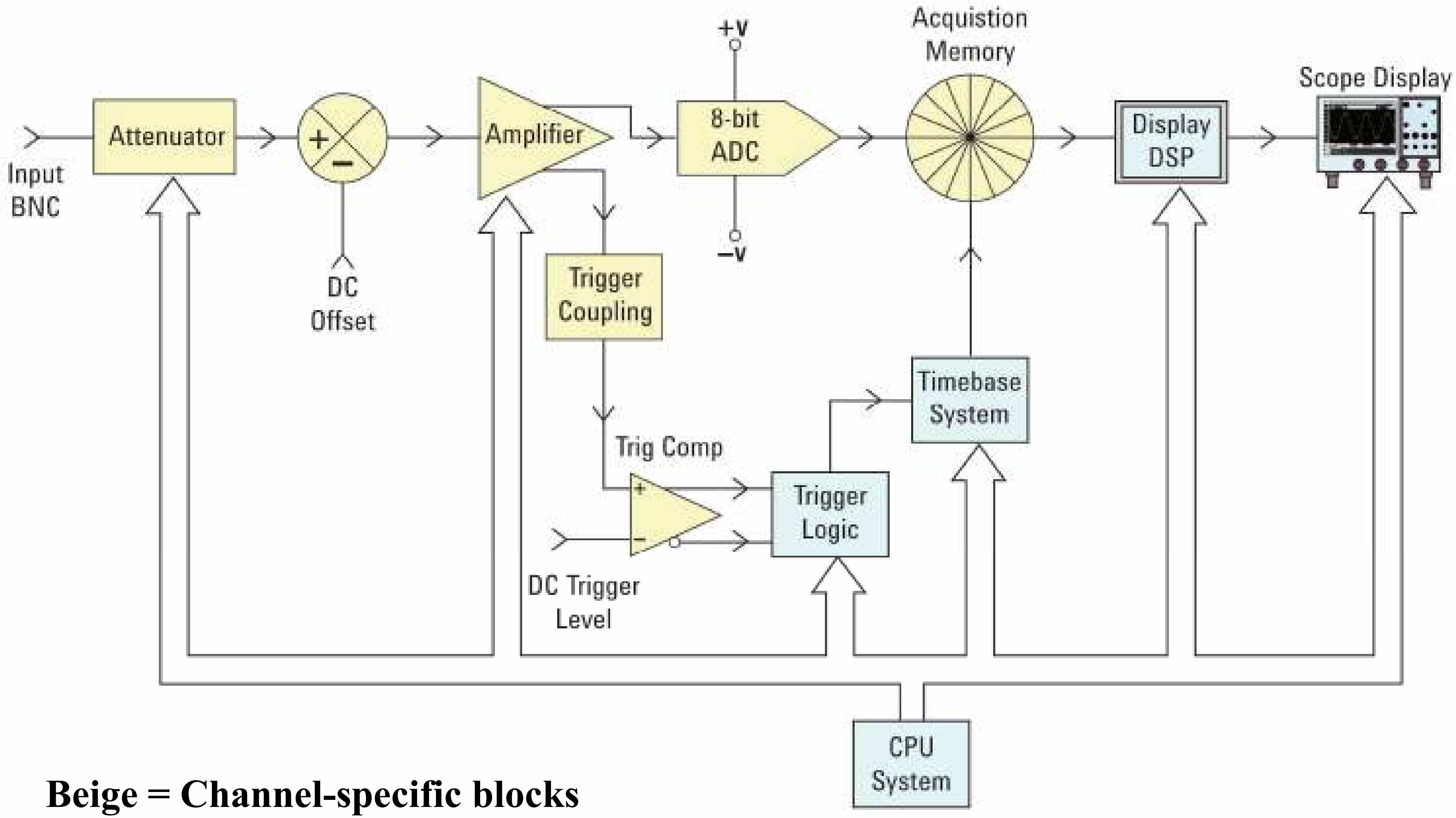
- Required BW for analog applications: ≥ 2X highest sine wave frequency.
- Required BW for digital applications: ≥ 5X highest digital clock rate.

Other Important DS Oscilloscope Specifications

- Sample Size (in bits) – 8 bits is minimum, 10, 12 or greater is better.
- Sample Rate (in samples/sec) – Should be ≥ 4X BW
- Memory Depth – Determines the longest waveforms that can be captured while still sampling at the scope's maximum sample rate.
- Number of Channels – Typically 2 or 4 channels.

- Waveform Update Rate – Faster update rates enhance probability of capturing infrequently occurring circuit problems.
- Display Quality – Size, resolution, number of levels of intensity gradation.
- Advanced Triggering Modes – Time-qualified pulse widths, Pattern, Video, Serial, Pulse Violation etc.

Generic DSO Theory of Operation



Beige = Channel-specific blocks
Blue = System blocks (supports all channels)

Do we want to go into more depth on ADCs?

Comparing the JyeTech DSO062 & DSO138

Both are based on using microcontrollers with the minimum of additional circuitry.

- The DSO062 uses the Atmel ATMega64

- The DSO138 uses the Cortex-M3 ARM processor (STM32F103C8) from ST

JyeTech DSO062 & DSO138 Specifications

Parameter	DSO062	DSO138
Sample size	8 bit	12 bit
Analogue Bandwidth	1MHz	200kHz
Sample Buffer Depth	256 bytes	1024 bytes
Sampling rate	2Msps	1Msps
Vertical Sensitivity	100mV/Div - 5V/Div	10mV/Div - 5V/Div
Timebase/Horizontal Range	0.5us/Div - 10m(minute)/Div	10us/Div - 500s/Div
Display	LCD monochrome (128x64)	2.4-inch TFT LCD (320 X 240 dotmatrix, 262K colors
Max input voltage	50Vpp	50V peak
Input Impedance	1M ohm	1M ohm

So what can you do with a DSO?

-practically everything you can do with an analogue scope

-plus everything that operating in the digital domain brings, including storage, replay, transformation and analysis

Summary

(Hopefully) you should have an appreciation of:

- what an oscilloscope is and its basic operation
- The basic architecture of a DSO
- Pros & cons of DSOs
- Important aspects of specs and what they mean
- Comparison of specifications of DSO062 & DSO138

Any more questions?