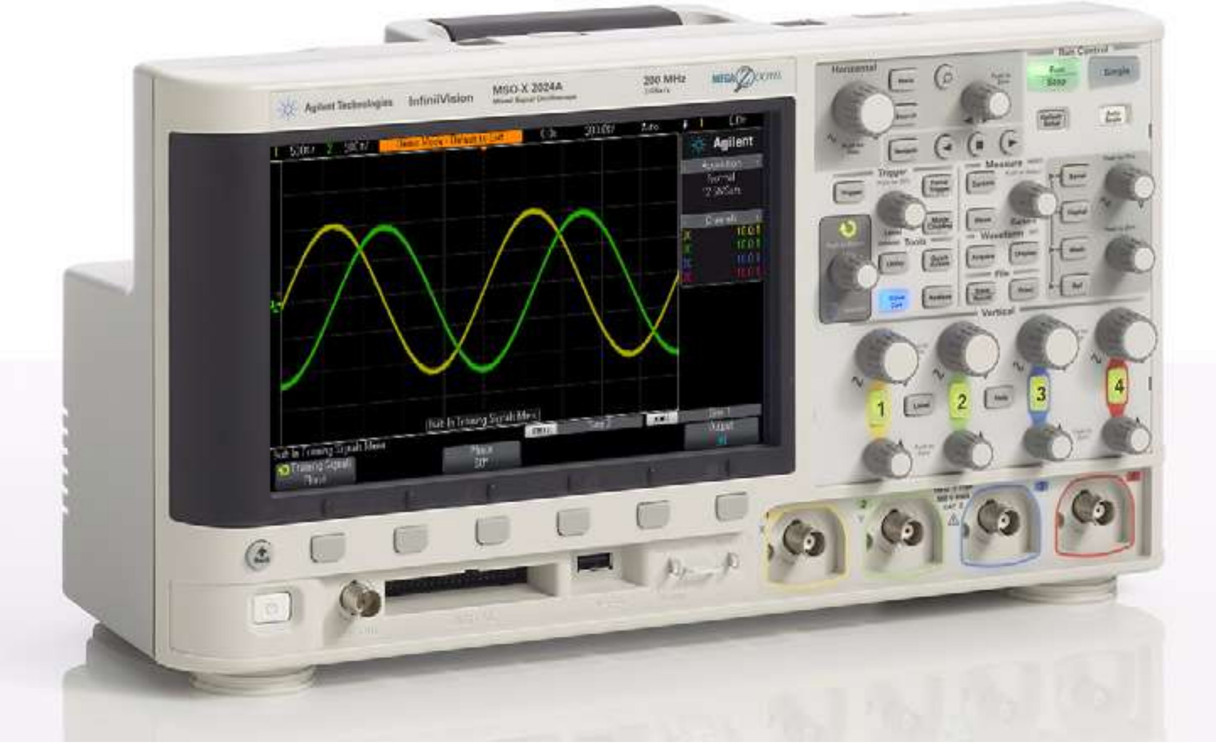
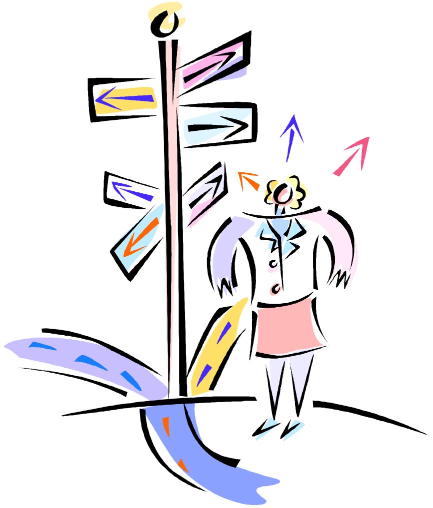
Oscilloscope Fundamentals

For Electrical Engineering and Physics Undergraduate Students



Agilent Technologies

Agenda



- What is an oscilloscope?
- Probing basics (low-frequency model)
- Making voltage and timing measurements
- Properly scaling waveforms on-screen
- Understanding oscilloscope triggering
- Oscilloscope theory of operation and performance specifications
- Probing revisited (dynamic/AC model and affects of loading)
- Using the DSOXEDK Lab Guide and Tutorial
- Additional technical resources

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 engineers and technicians to test, verify, and debug electronic designs.
- Oscilloscopes will be the primary instrument that you will use in your EE/Physics labs to test assigned experiments.

Terms of Endearment (what they are called)

Scope – Most commonly used terminology

DSO – Digital Storage Oscilloscope

Digital Scope

Digitizing Scope

Analog Scope – Older technology oscilloscope, but still around today.

CRO – Cathode Ray Oscilloscope (pronounced "crow"). Even though most scopes no longer utilize cathode ray tubes to display waveforms, Aussies and Kiwis still affectionately refer to them as their CROs.

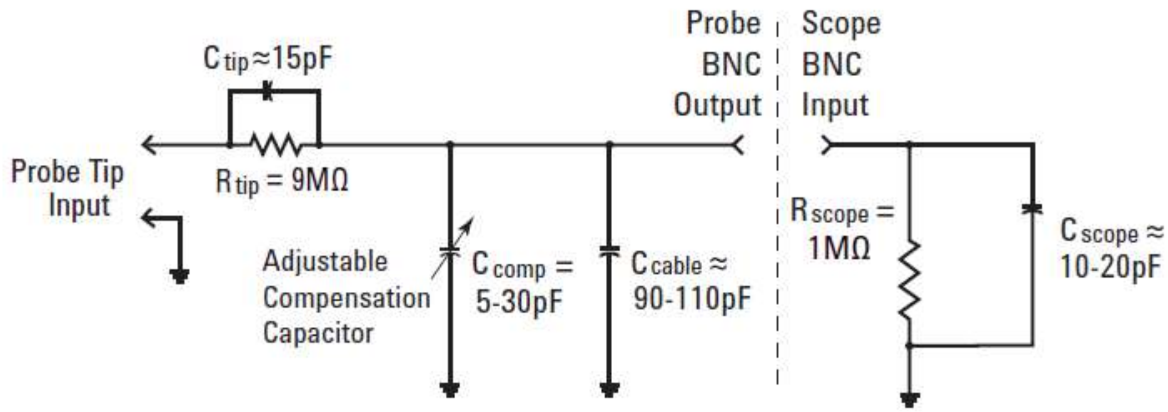
O-Scope

MSO – Mixed Signal Oscilloscope (includes logic analyzer channels of acquisition)

Probing Basics

- 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



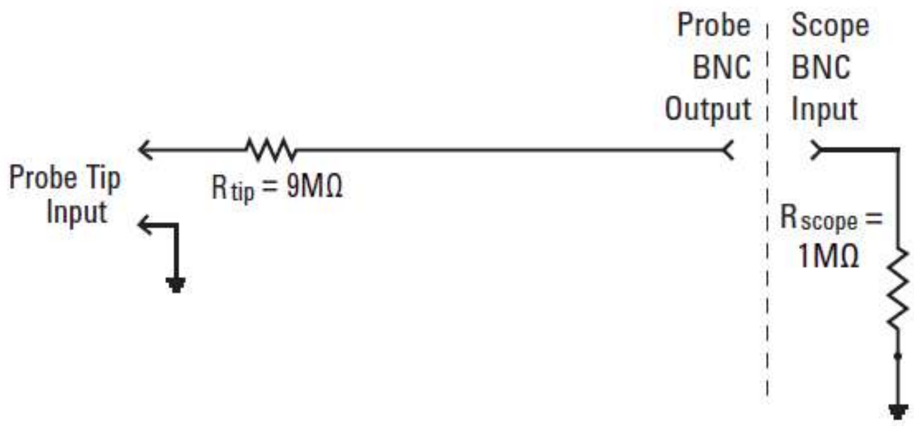
Passive 10:1 Probe Model

<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!

Low-frequency/DC Model



Passive 10:1 Probe Model

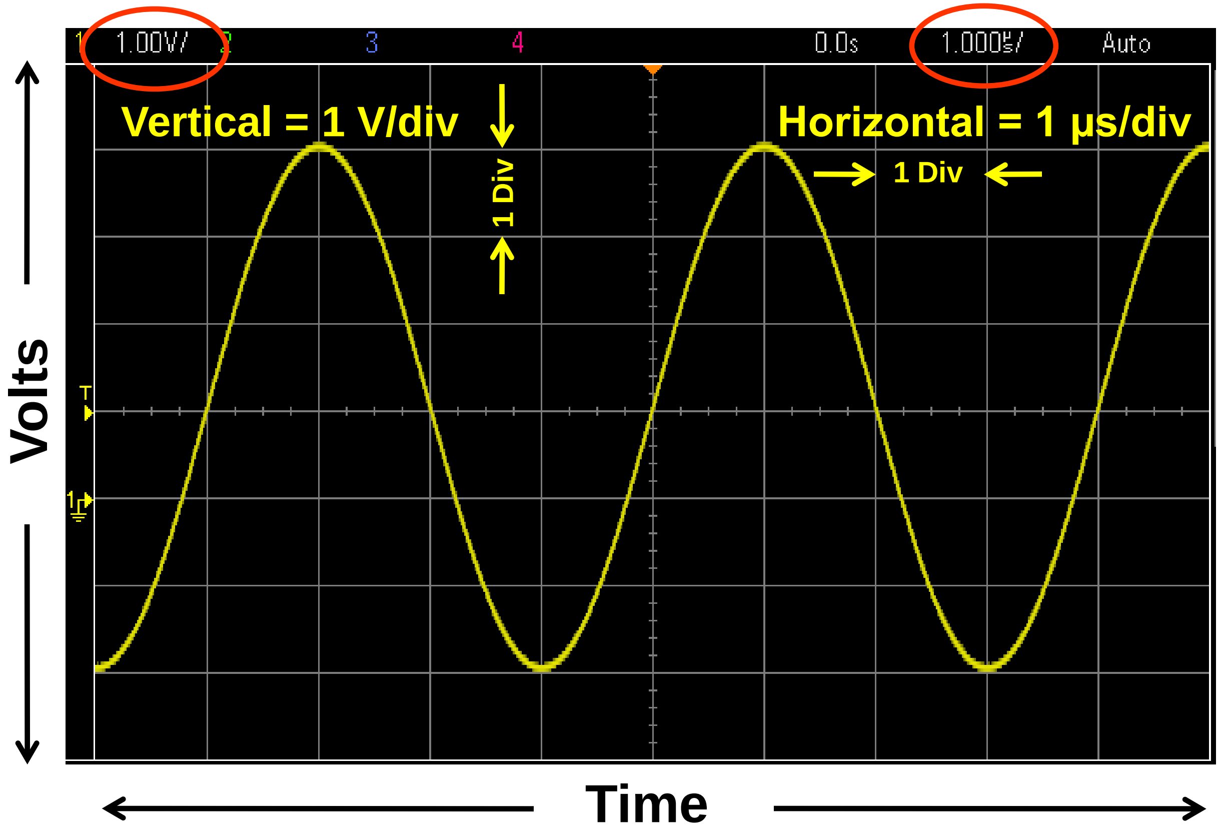
Low-frequency/DC Model: Simplifies to a 9-MΩ resistor in series with the scope's 1-MΩ input termination.

Probe Attenuation Factor:

- ✓ Some scopes such as Agilent's 3000 X-Series automatically detect 10:1 probes and adjust all vertical settings and voltage measurements relative to the probe tip.
- ✓ Some scopes such as Agilent's 2000 X-Series require manual entry of a 10:1 probe attenuation factor.

Dynamic/AC Model: Covered later and during Lab #5.

Understanding the Scope's Display

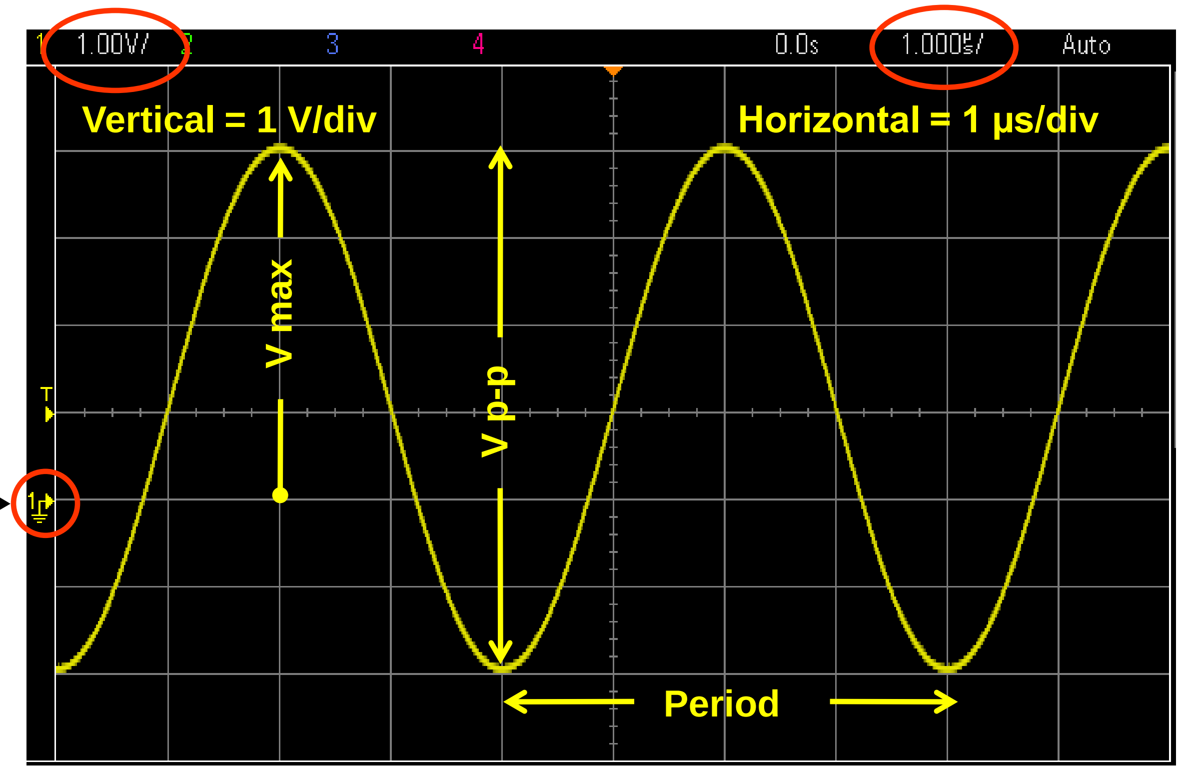


- Waveform display area shown with grid lines (or divisions).
- Vertical spacing of grid lines relative to Volts/division setting.
- Horizontal spacing of grid lines relative to sec/division setting.

Making Measurements – by visual estimation

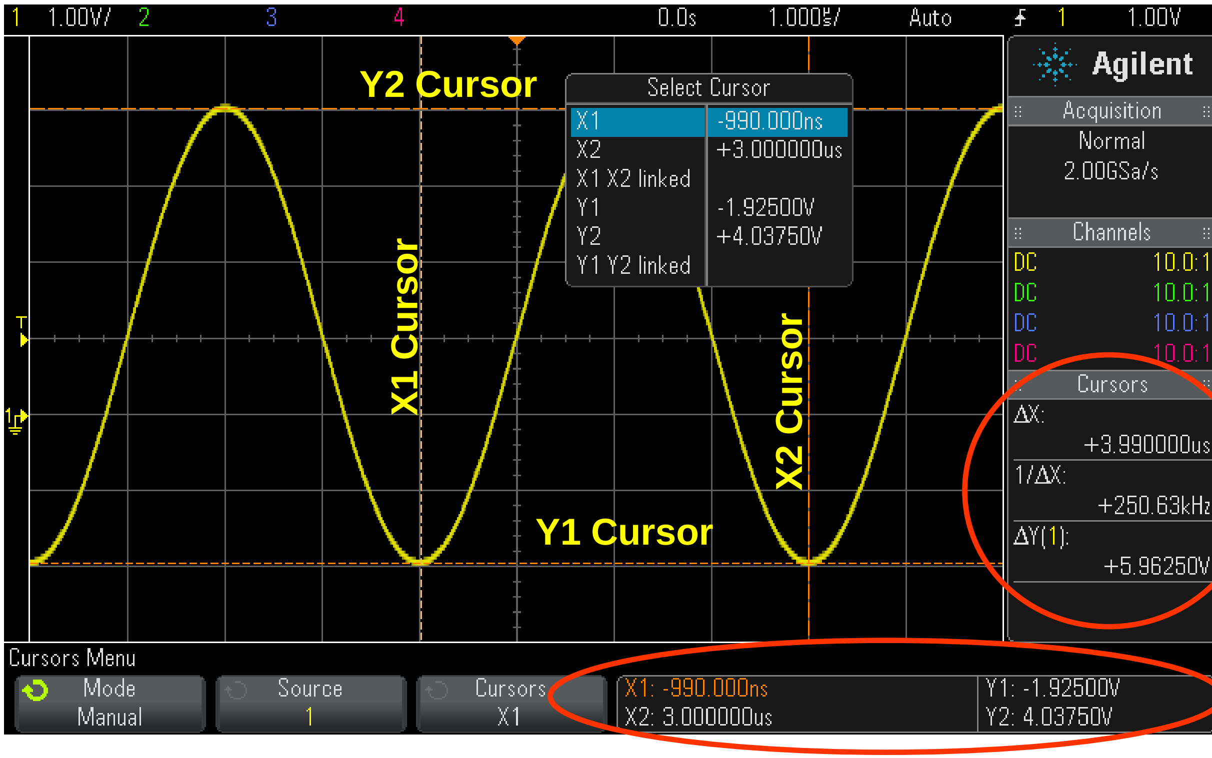
The most common measurement technique

Ground level (0.0 V) indicator



- Period (T) = 4 divisions x 1 µs/div = 4 µs, Freq = 1/T = 250 kHz.
- V p-p = 6 divisions x 1 V/div = 6 V p-p
- V max = +4 divisions x 1 V/div = +4 V, V min = ?

Making Measurements – using cursors



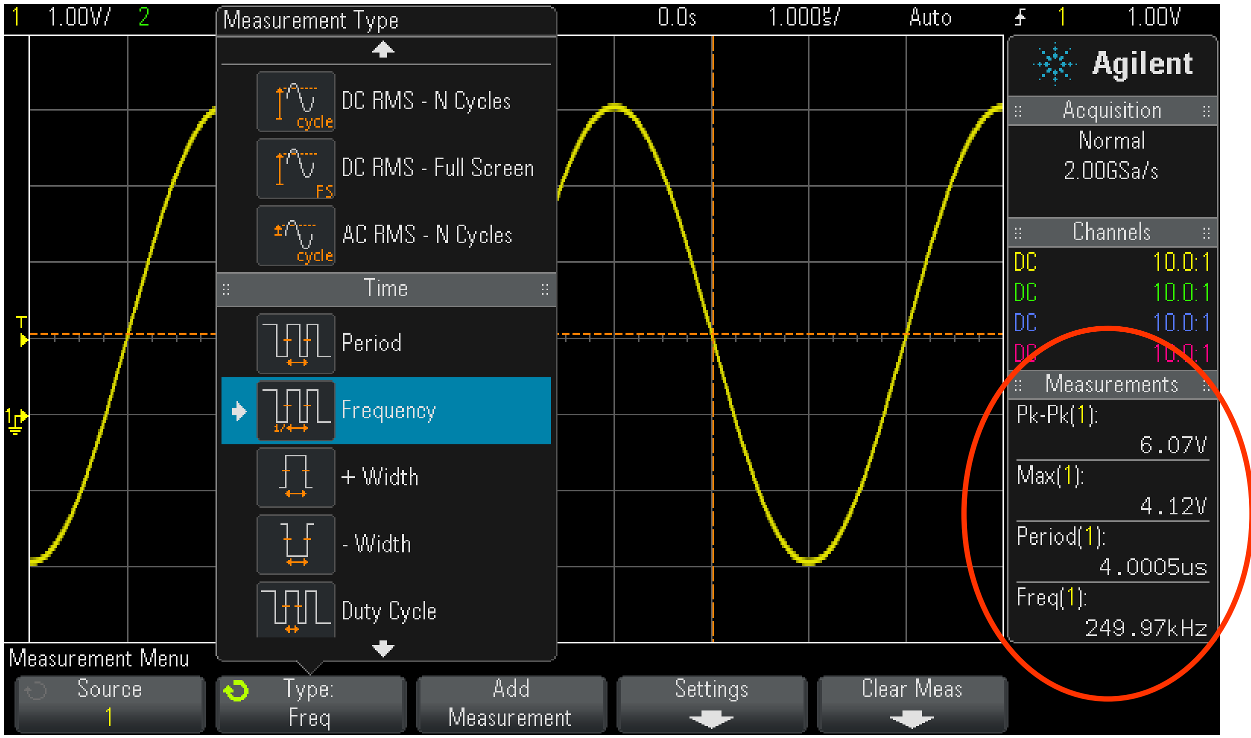
Cursor Controls

Δ Readout

Absolute V & T Readout

- Manually position X & Y cursors to desired measurement points.
- Scope automatically multiplies by the vertical and horizontal scaling factors to provide absolute and delta measurements.

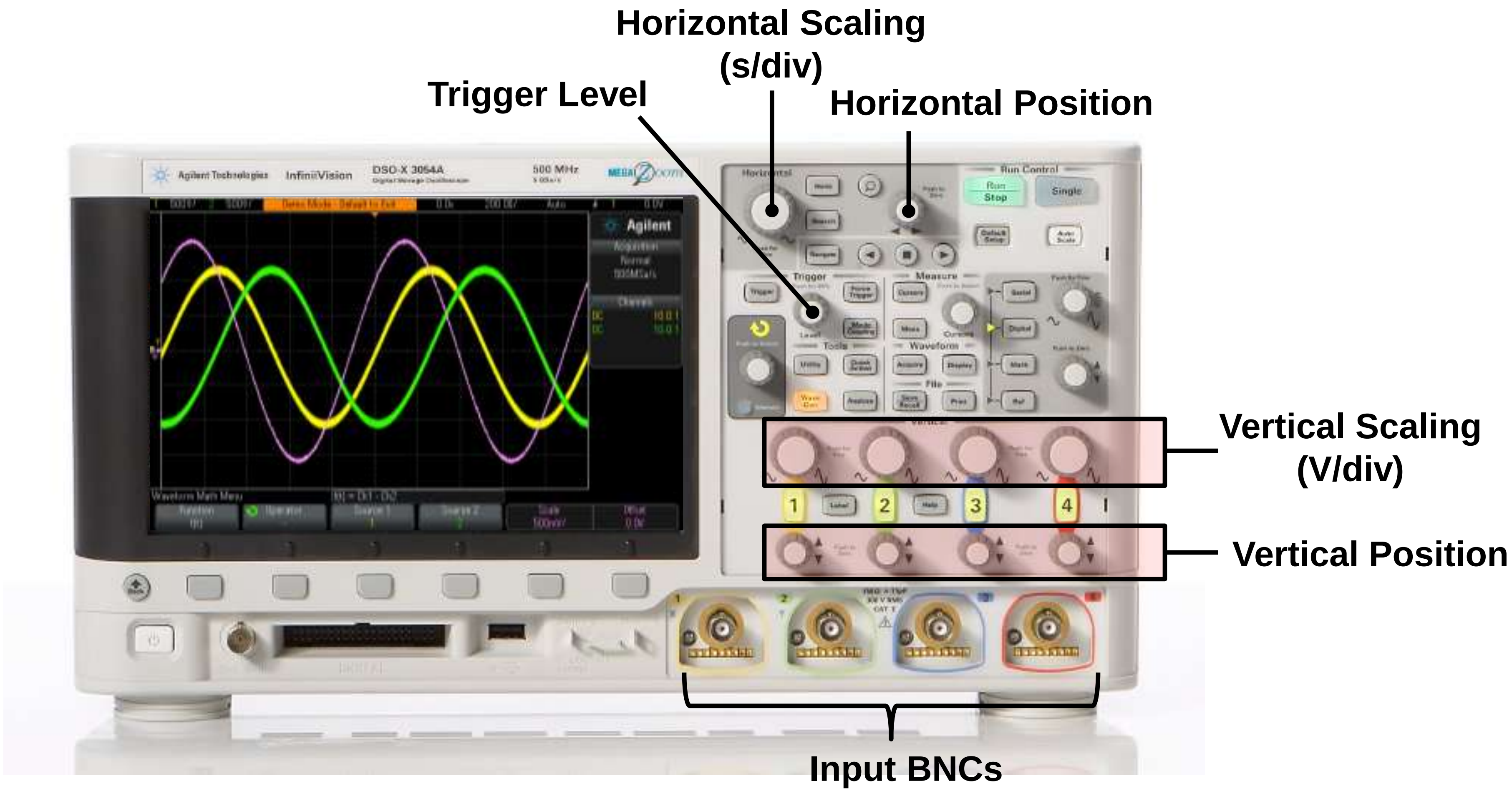
Making Measurements – using the scope's automatic parametric measurements



Readout

- Select up to 4 automatic parametric measurements with a continuously updated readout.

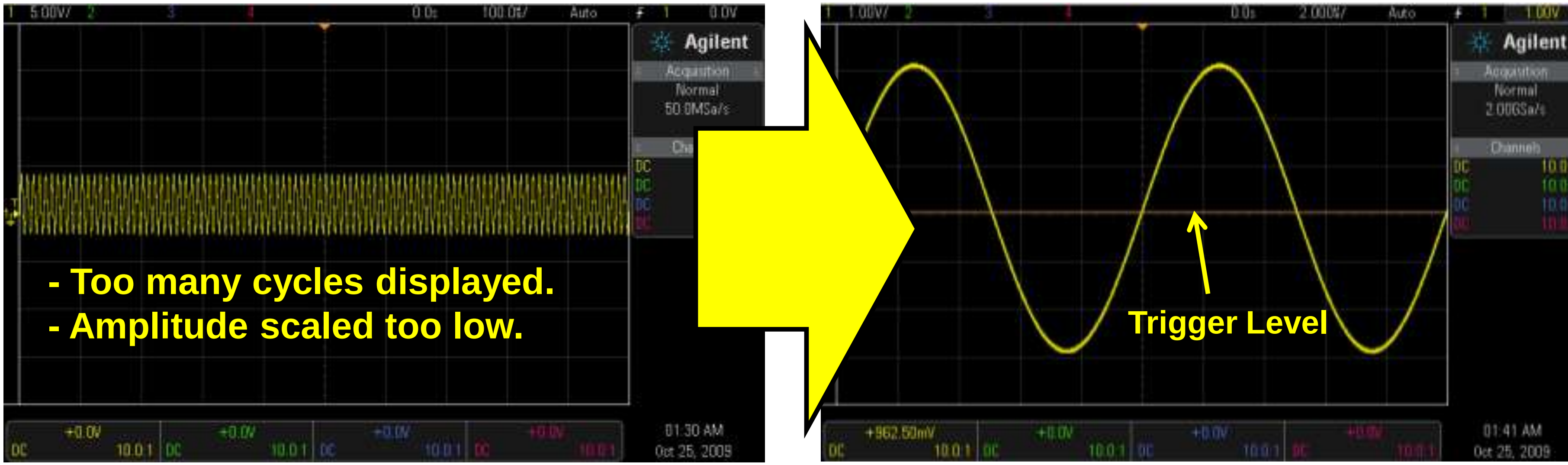
Primary Oscilloscope Setup Controls



Agilent's InfiniiVision 2000 & 3000 X-Series Oscilloscope

Properly Scaling the Waveform

Initial Setup Condition (example) | **Optimum Setup Condition**



- Adjust **V/div** knob until waveform fills most of the screen vertically.
- Adjust vertical **Position** knob until waveform is centered vertically.
- Adjust **<u>s/div</u>** knob until just a few cycles are displayed horizontally.
- Adjust **<u>Trigger Level</u>** knob until level set near middle of waveform vertically.

Setting up the scope's waveform scaling is an iterative process of making front panel adjustments until the desired "picture" is displayed on-screen.

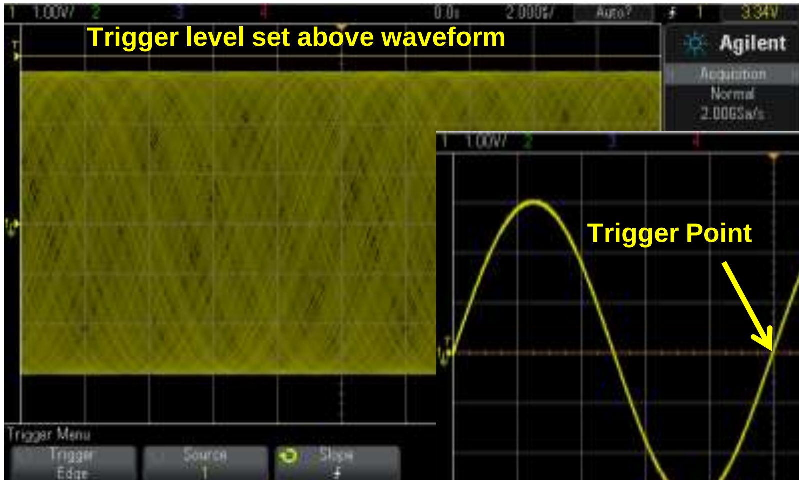
Understanding Oscilloscope Triggering

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

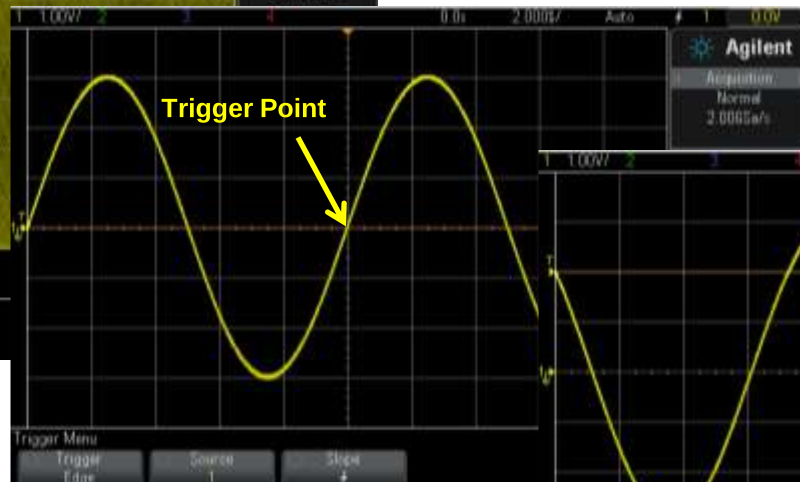
- Think of oscilloscope “triggering” as “synchronized picture taking”.
- One waveform “picture” consists of many consecutive digitized samples.
- “Picture Taking” must be synchronized to a unique point on the waveform that repeats.
- Most common oscilloscope triggering is based on synchronizing acquisitions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

A photo finish horse race is analogous to oscilloscope triggering

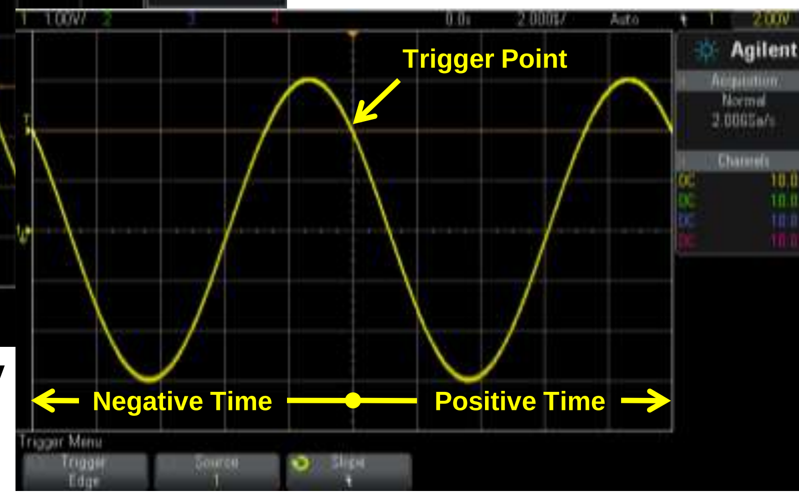
Triggering Examples



Untriggered
(unsynchronized picture taking)



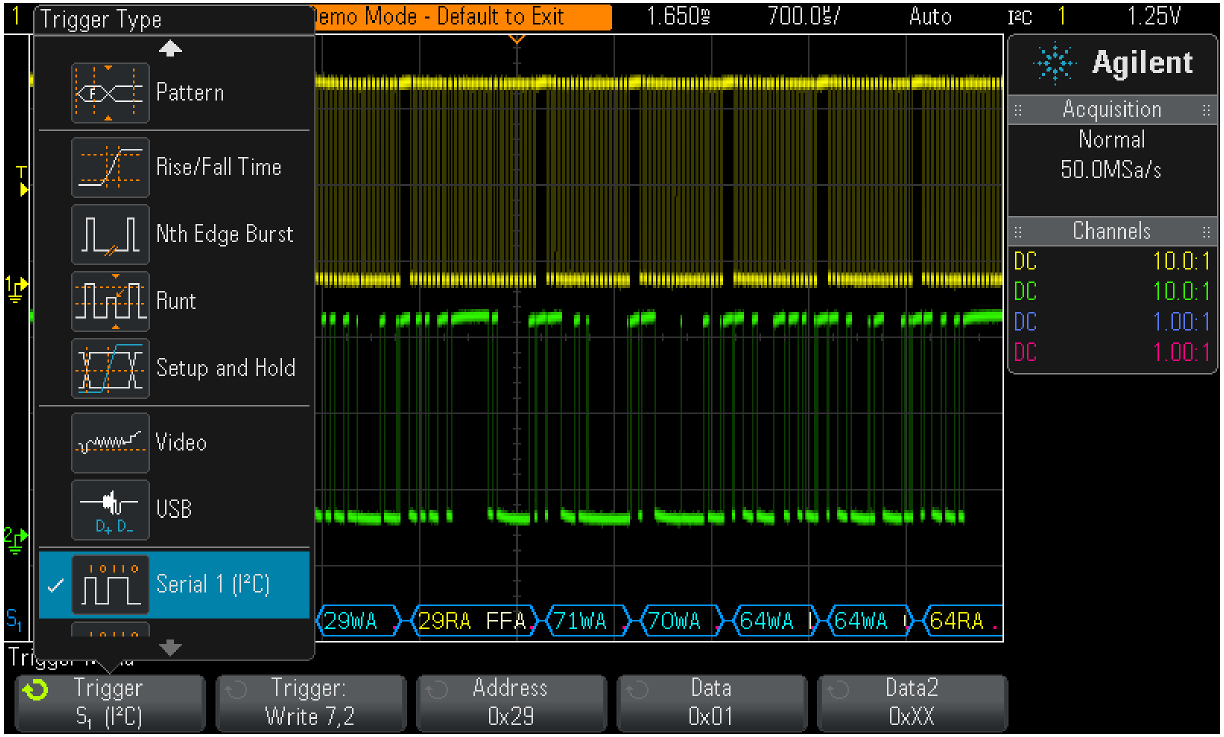
Trigger = Rising edge @ 0.0 V



Trigger = Falling edge @ +2.0 V

- **Default trigger location (time zero) on DSOs = center-screen (horizontally)**
- **<u>Only</u> trigger location on older analog scopes = left side of screen**

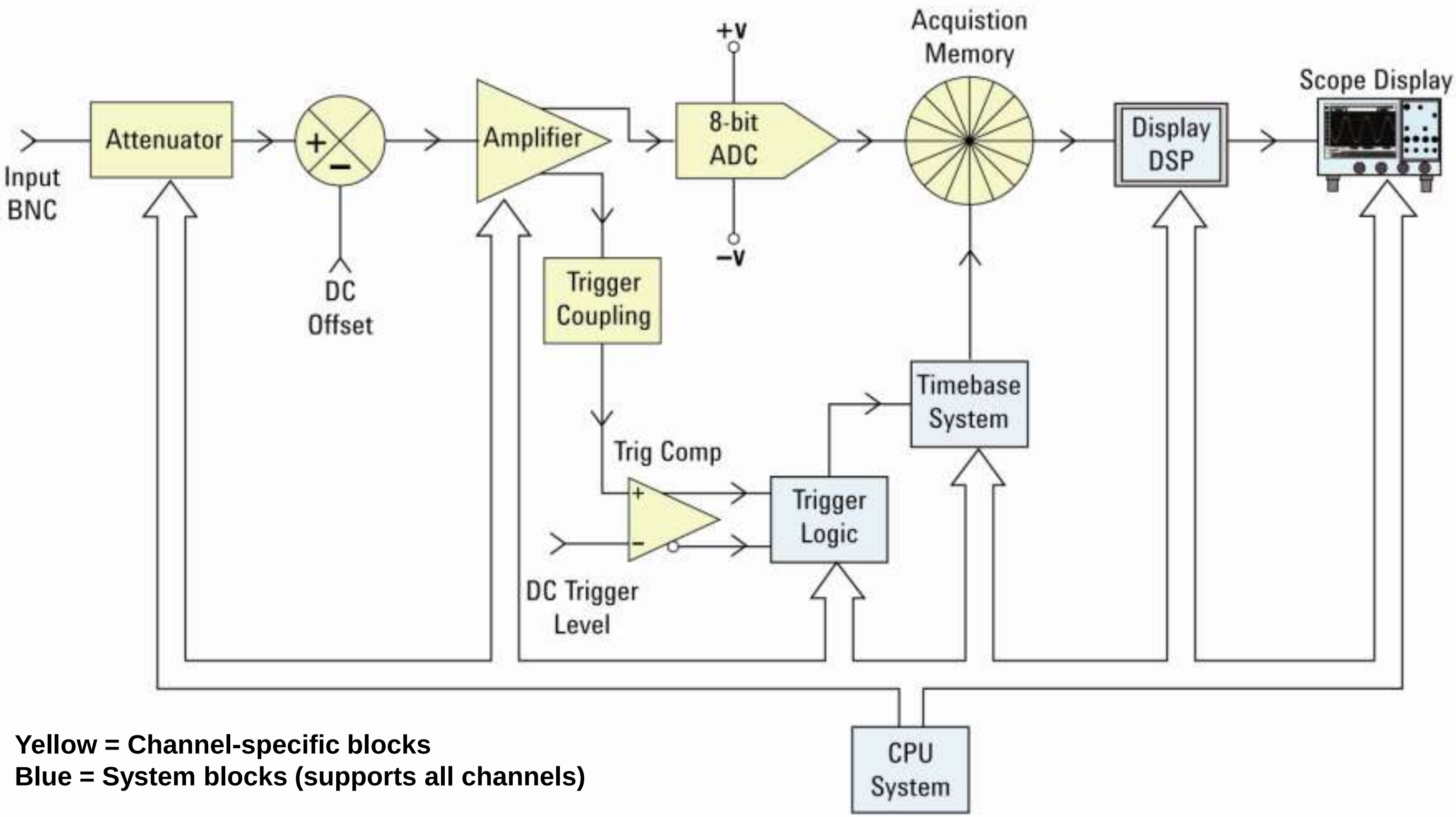
Advanced Oscilloscope Triggering



Example: Triggering on an I²C serial bus

- Most of your undergraduate lab experiments will be based on using standard "edge" triggering
- Triggering on more complex signals requires advanced triggering options.
- .

Oscilloscope Theory of Operation

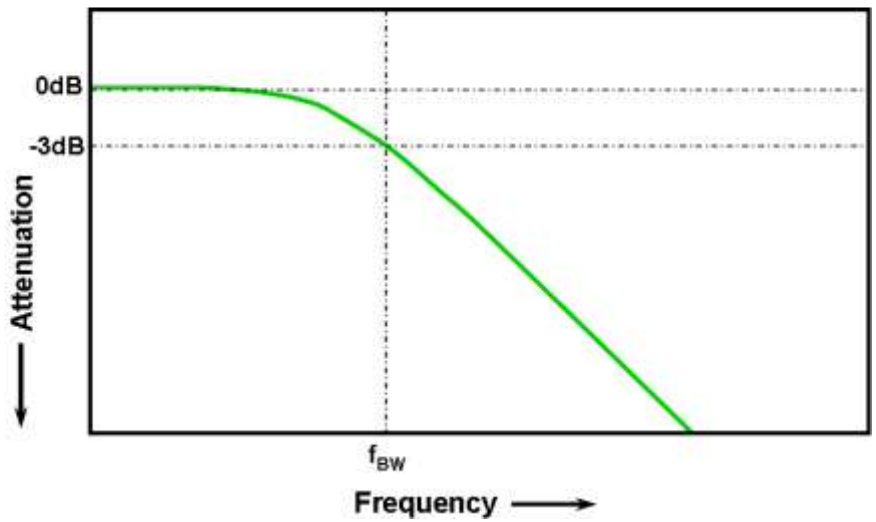


Yellow = Channel-specific blocks
Blue = System blocks (supports all channels)

DSO Block Diagram

Oscilloscope Performance Specifications

"Bandwidth" is the most important oscilloscope specification

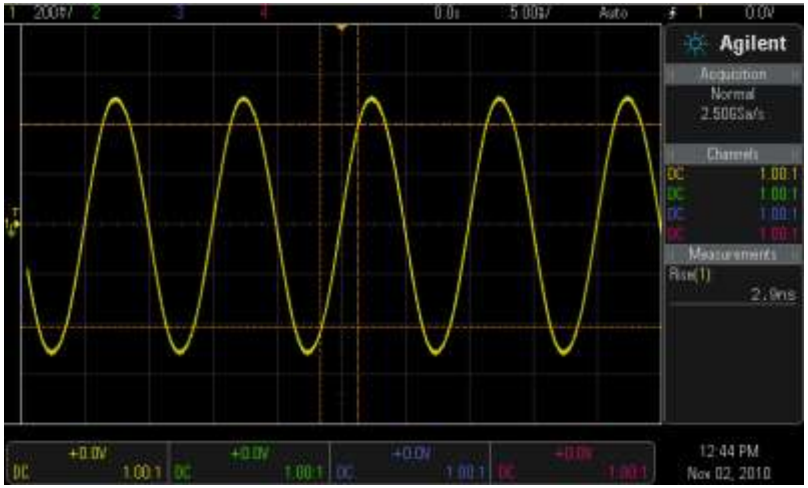


Oscilloscope "Gaussian" Frequency Response

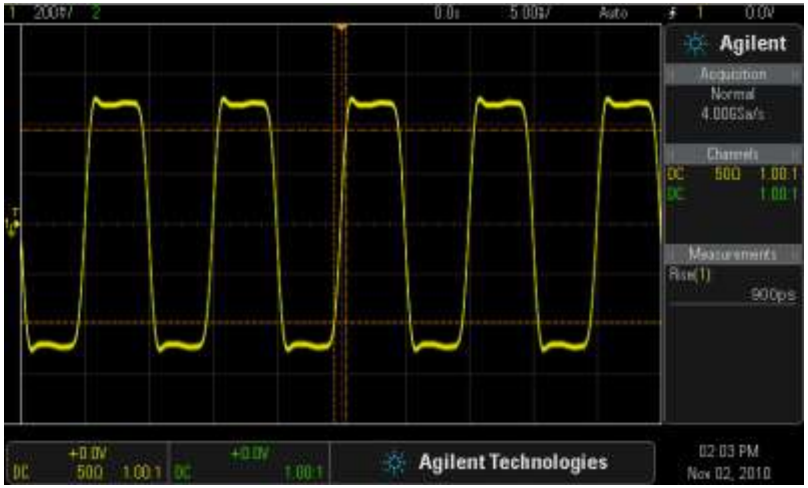
- All oscilloscopes exhibit a low-pass frequency response.
- The frequency where an input sine wave is attenuated by 3 dB defines the scope's bandwidth.
- -3 dB equates to ~ -30% amplitude error (-3 dB = 20 Log$\frac{Vo}{Vi}$).

Selecting the Right Bandwidth

Input = 100-MHz Digital Clock



Response using a 100-MHz BW scope



Response using a 500-MHz BW scope

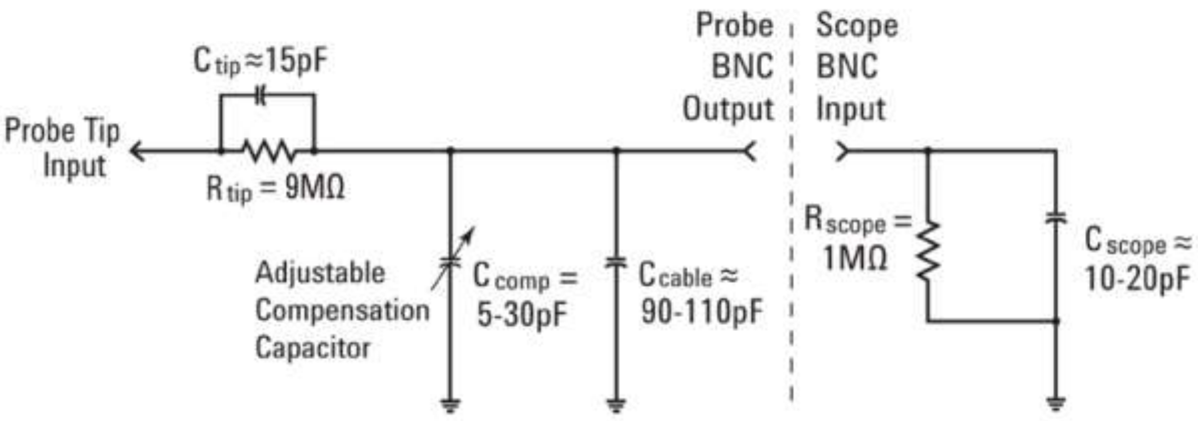
- Required BW for analog applications: ≥ 3X highest sine wave frequency.
- Required BW for digital applications: ≥ 5X highest digital clock rate.
- More accurate BW determination based on signal edge speeds (refer to “Bandwidth” application note listed at end of presentation)

Other Important Oscilloscope Specifications

- 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. MSO models add 8 to 32 channels of digital acquisition with 1-bit resolution (high or low).

- 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 (edge speed, Setup/Hold time, Runt), etc.

Probing Revisited - Dynamic/AC Probe Model



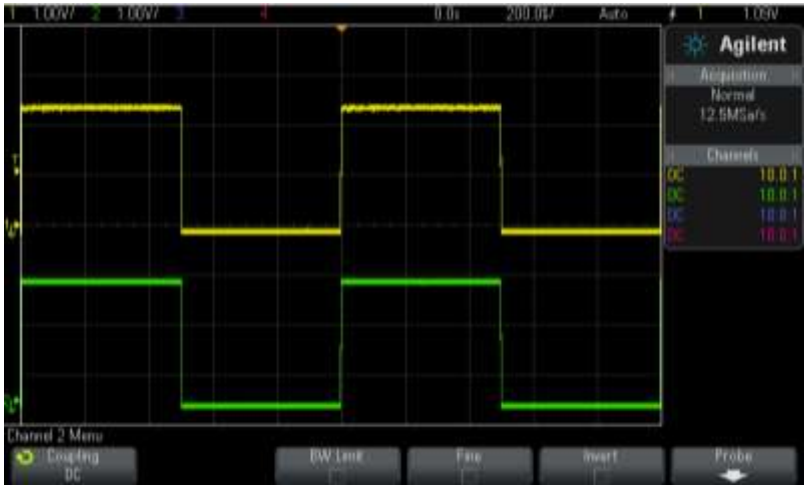
Passive 10:1 Probe Model

- $\boldsymbol{C_{scope}}$ and $\boldsymbol{C_{cable}}$ are inherent/parasitic capacitances (not intentionally designed-in)
- $\boldsymbol{C_{tip}}$ and $\boldsymbol{C_{comp}}$ are intentionally designed-in to compensate for $\boldsymbol{C_{scope}}$ and $\boldsymbol{C_{cable}}$.
- With properly adjusted probe compensation, the dynamic/AC attenuation due to frequency-dependant capacitive reactances should match the designed-in resistive voltage-divider attenuation (10:1).

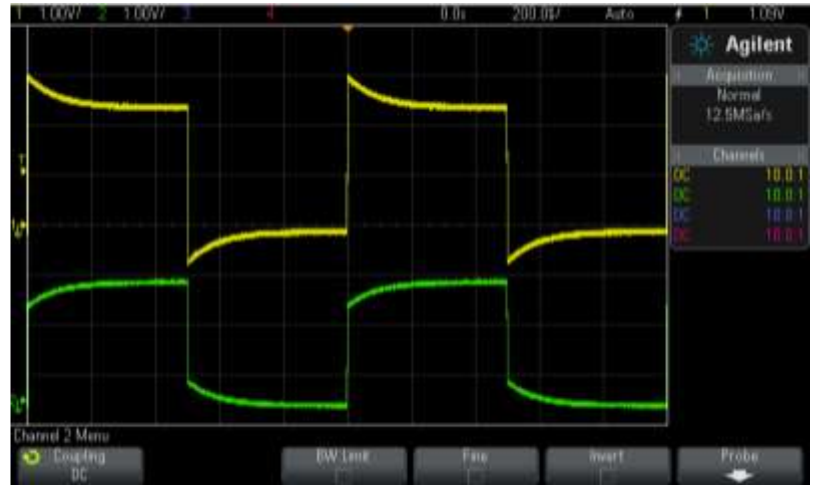
$$\frac{1}{2\pi f C_{\text{tip}}} = \frac{9}{2\pi f C_{\text{parallel}}}$$

Where $C_{parallel}$ is the parallel combination of C_{comp} + C_{cable} + C_{scope}

Compensating the Probes



Proper Compensation

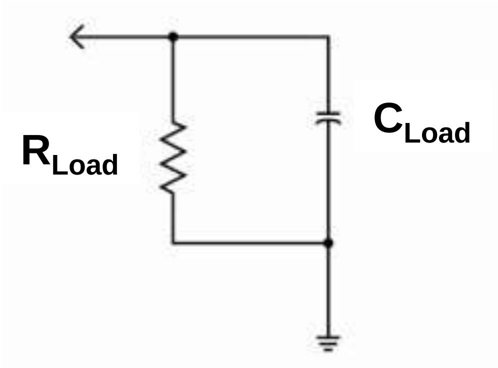


Channel-1 (yellow) = Over compensated
Channel-2 (green) = Under compensated

- Connect Channel-1 and Channel-2 probes to the “Probe Comp” terminal (same as Demo2).
- Adjust V/div and s/div knobs to display both waveforms on-screen.
- Using a small flat-blade screw driver, adjust the variable probe compensation capacitor (C_{comp}) on both probes for a flat (square) response.

Probe Loading

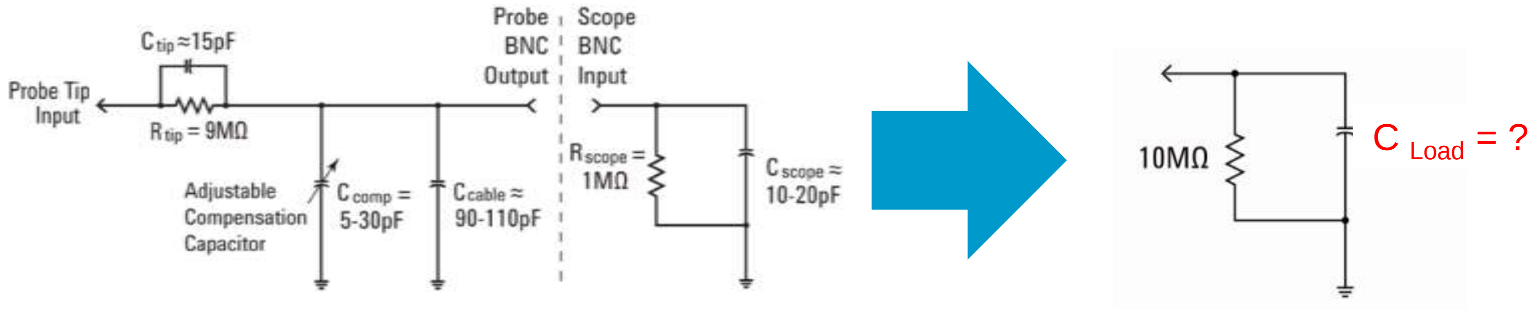
- The probe and scope input model can be simplified down to a single resistor and capacitor.



Probe + Scope Loading Model

- Any instrument (not just scopes) connected to a circuit becomes a part of the circuit under test and will affect measured results… especially at higher frequencies.
- “Loading” implies the negative affects that the scope/probe may have on the circuit’s performance.

Assignment



1. Assuming $\boldsymbol{C_{scope}}$ = 15pF, $\boldsymbol{C_{cable}}$ = 100pF and $\boldsymbol{C_{tip}}$ = 15pF, compute $\boldsymbol{C_{comp}}$ if properly adjusted. $\boldsymbol{C_{comp}}$ = ______
2. Using the computed value of $\boldsymbol{C_{comp}}$, compute $\boldsymbol{C_{Load}}$. $\boldsymbol{C_{Load}}$ = ______
3. Using the computed value of $\boldsymbol{C_{Load}}$, compute the capacitive reactance of $\boldsymbol{C_{Load}}$ at 500 MHz. $\boldsymbol{X_{C\text{-}Load}}$ = ______

Using the Oscilloscope Lab Guide and Tutorial

Homework ***– Read the following sections before your 1st oscilloscope lab session:***

Section 1 – Getting Started

- ✓ Oscilloscope Probing
- ✓ Getting Acquainted with the Front Panel

Appendix A – Oscilloscope Block Diagram and Theory of Operation

Appendix B – Oscilloscope Bandwidth Tutorial

Hands-on Oscilloscope Labs

Section 2 – Basic Oscilloscope and WaveGen Measurement Labs (6 individual labs)

Section 3 – Advanced Oscilloscope Measurement Labs (9 optional labs that your professor may assign)

Oscilloscope Lab Guide and Tutorial
Download @ www.agilent.com/find/EDK

Hints on how to follow lab guide instructions

Bold words in brackets, such as **[Help]**, refers to a front panel key.

“Softkeys” refer to the 6 keys/buttons below the scope’s display. The function of these keys change depending upon the selected menu.

Softkey Labels

Softkeys

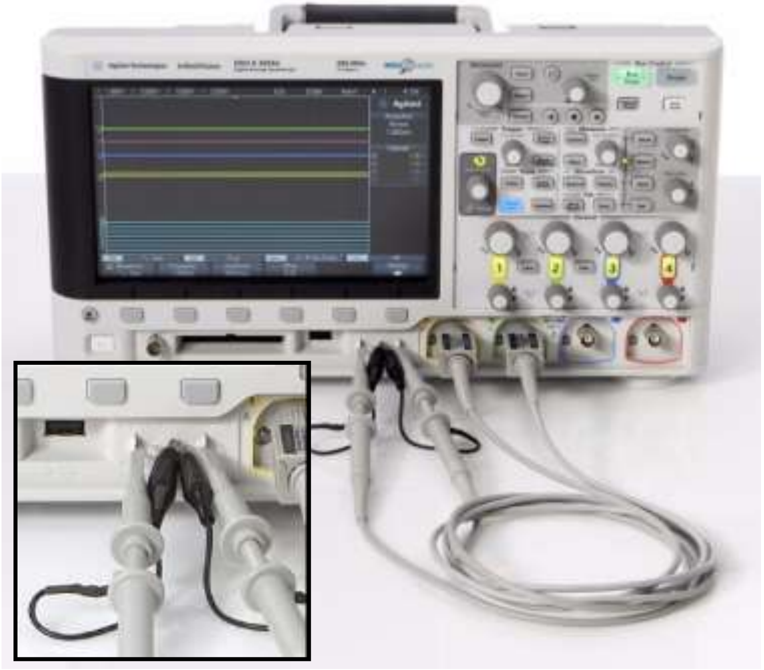
A softkey labeled with the curled green arrow ( ) indicates that the general-purpose “**Entry**” knob controls that selection or variable.

Entry Knob

Accessing the Built-in Training Signals

Most of the oscilloscope labs are built around using a variety of training signals that are built into the Agilent 2000 or 3000 X-Series scopes if licensed with the DSOXEDK Educator's Training Kit option.

1. Connect one probe between the scope's channel-1 input BNC and the terminal labeled "Demo1".
2. Connect another probe between the scope's channel-2 input BNC and the terminal labeled "Demo2".
3. Connect both probe's ground clips to the center ground terminal.
4. Press **[Help]**; then press the **Training Signals** softkey.



Connecting to the training signals test terminals using 10:1 passive probes

Additional Technical Resources Available from Agilent Technologies

Application Note	Publication #
Evaluating Oscilloscope Fundamentals	5989-8064EN
Evaluating Oscilloscope Bandwidths for your Applications	5989-5733EN
Evaluating Oscilloscope Sample Rates vs. Sampling Fidelity	5989-5732EN
Evaluating Oscilloscopes for Best Waveform Update Rates	5989-7885EN
Evaluating Oscilloscopes for Best Display Quality	5989-2003EN
Evaluating Oscilloscope Vertical Noise Characteristics	5989-3020EN
Evaluating Oscilloscopes to Debug Mixed-signal Designs	5989-3702EN
Evaluating Oscilloscope Segmented Memory for Serial Bus Applications	5990-5817EN

http://cp.literature.agilent.com/litweb/pdf/xxxx-xxxxEN.pdf

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Questions and Answers

Q&A