Tektronix

스코프, 간편하게 측정하기:
2시리즈 MSO
오실로스코프 교육

Contents

1. Introduction

2. Oscilloscope Fundamentals

- Bandwidth
- Sample Rate / Record Length
- Trigger System
- Probes

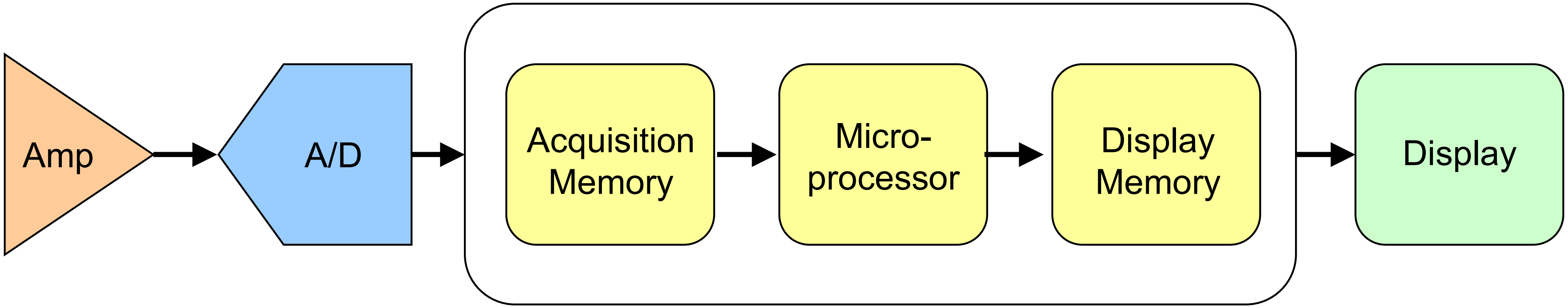
3. Advanced Features

- Horizontal/Acquisition setup
- Acquisition Mode
- Measurement
- Hori/Acq – Acquisition setup

Introduction

How Does an Oscilloscope Work?

- Signal Processing on the oscilloscope



Scope bandwidth and Probe bandwidth

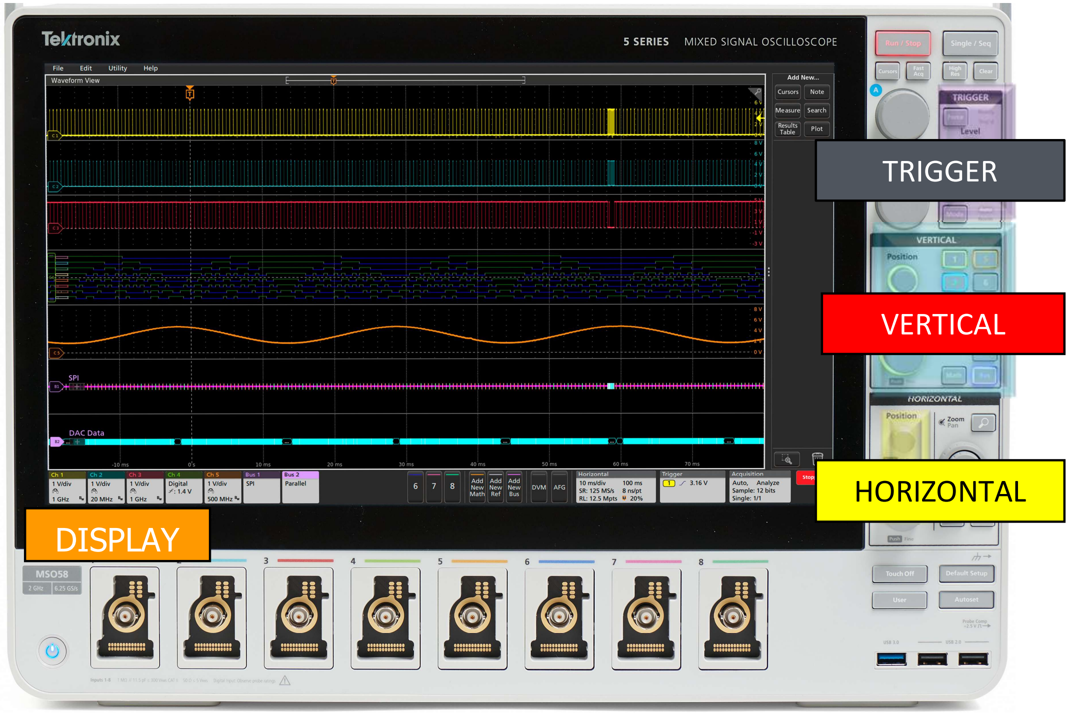
Sample rate

Record length

Trigger and Signal processing

Oscilloscope structure

MSO2 시리즈



MSO6B 시리즈

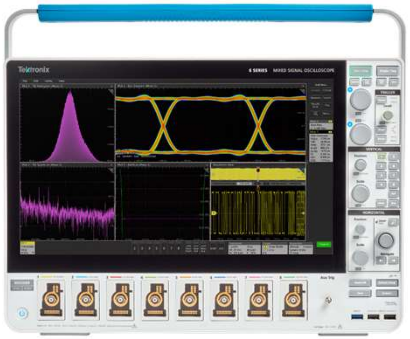
Real Time Oscilloscope Products

- **Basic Scopes**
  - TPS, TBS, TDS Series
- **Mixed Signal Scopes(MSO Series)**
- **Mixed Domain Scopes(MDO Series)**
- **High Performance Scopes (DPO70KC/DX/SX series High Performance Scope)**

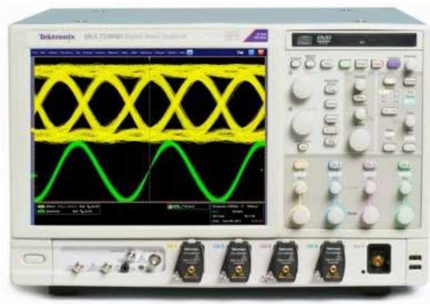
~ 2GHz | **~ 10GHz** | **13GHz ~ 70GHz**

MSO2 Series

MDO3 Series

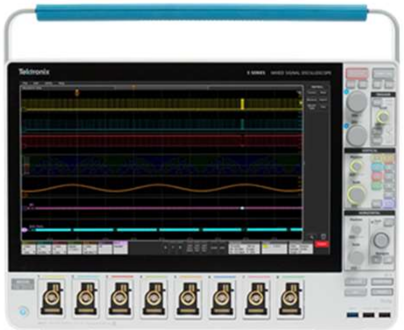


MSO6 Series



DPO70000 Series

MSO4 Series



MSO5 Series

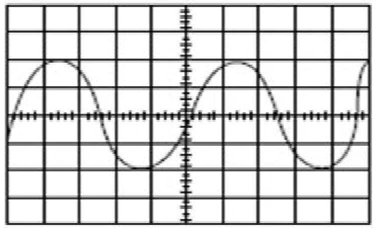
DPO70000SX Series

Oscilloscope

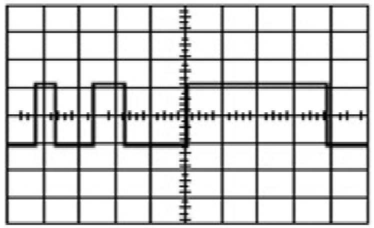
1. Observe.
   O.S.C observe the change of an electrical signal over time.



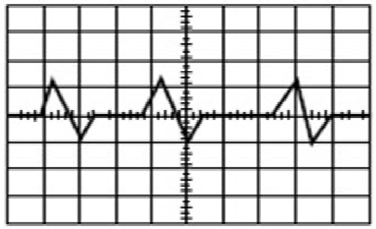

2. Display.
   O.S.C can display the observed waveform.



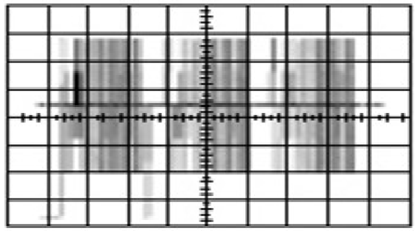
Sine Waves



Square & Rectangular Waves



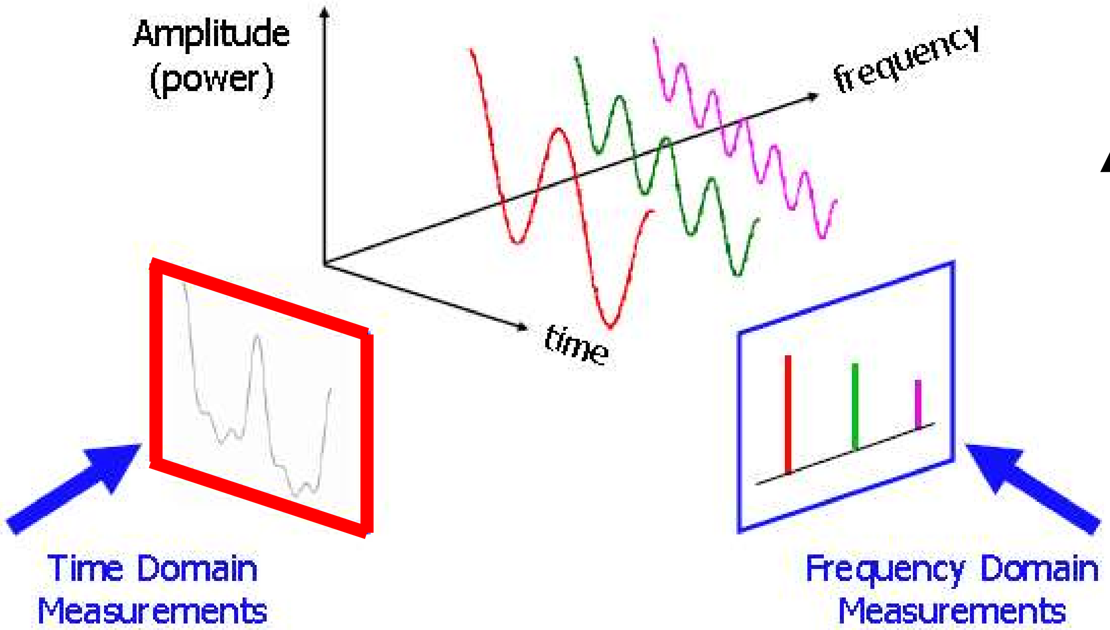
Sawtooth & Triangle Waves

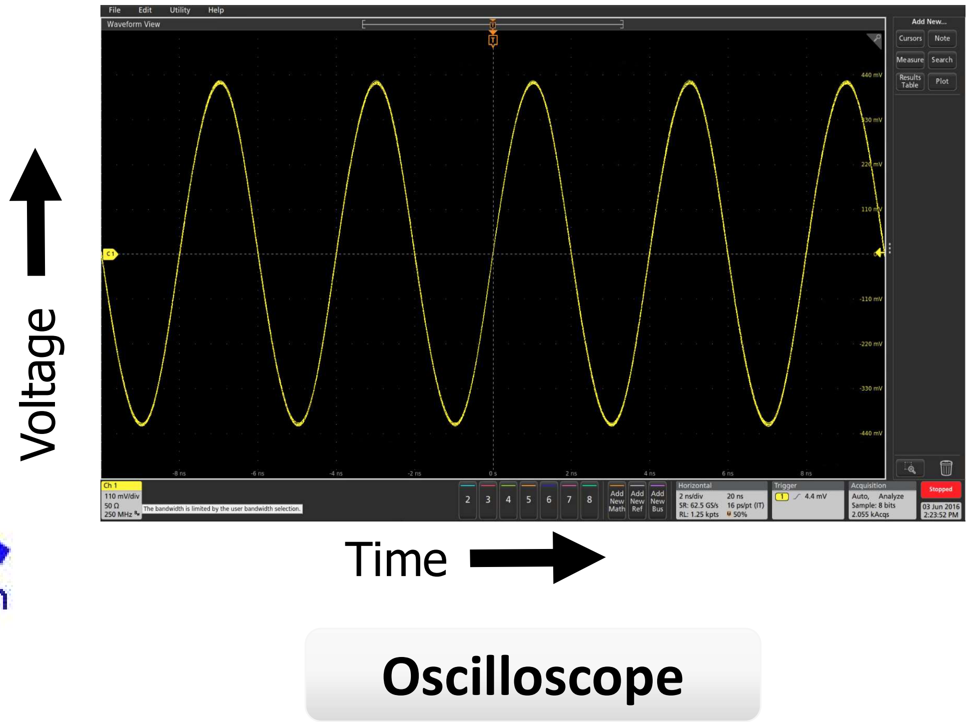


Complex Waves

What is the Oscilloscope?

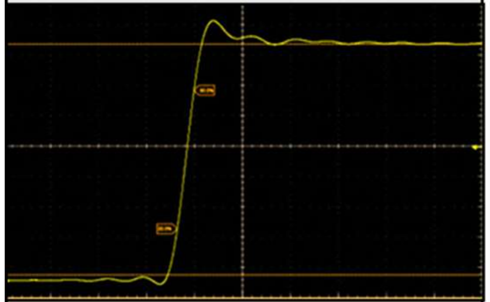
- Draws a graph of an electrical signal over time
    - Vertical (Y) axis is voltage or Current
    - Horizontal (X) axis is time





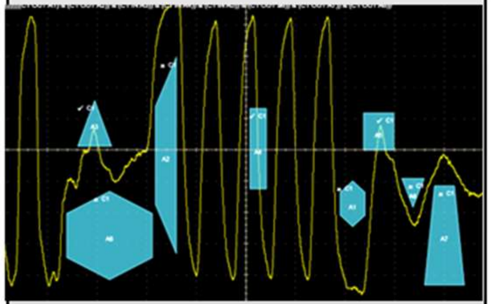
Oscilloscope Capabilities

Discover



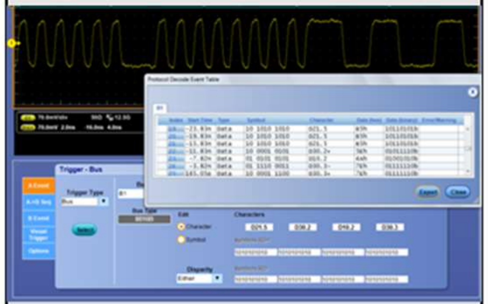
- Accurate signal representation
- Multi-channel acquisition without compromises
- Highly visible waveform content

Capture



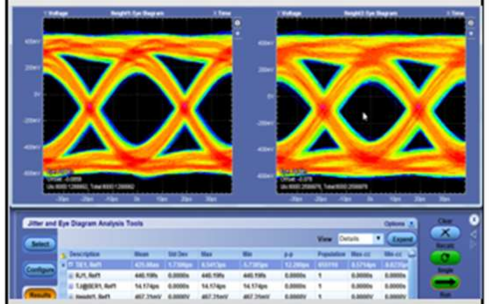
- Complex signal event capture
- Connectivity to DUT with high signal fidelity
- Access to decoded serial bus traffic

Search



- Easy verification through millions of sample points
- Long record length for timing analysis across clock cycles

Analyze



- Advanced jitter separation methods
- Accurate Serial Data compliance tests
- Fast data access for deeper analysis

Hands-on Lab:#1

Basic Operation and UI

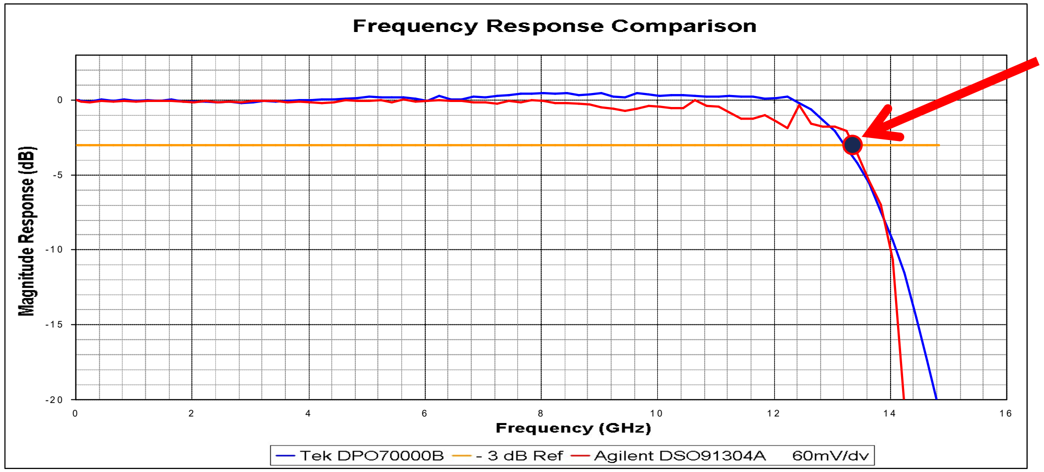
- **Front panel button and knob**
- **Windows and menus**

1. **Vertical , Horizontal , Trigger**
2. **SAVE and Recall(wfm,screen, setup, measurement)**
3. **Measurement**
4. **Usability of Scope**
5. **Badge**

Bandwidth

Bandwidth

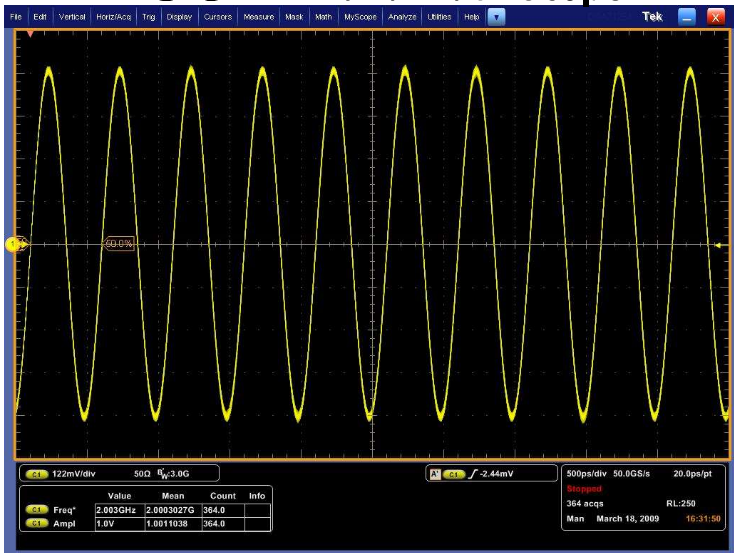
– Defined with Sine wave



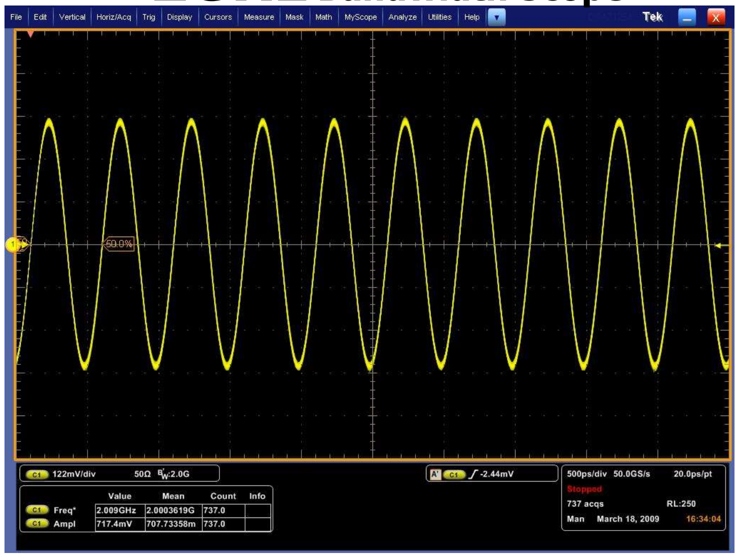
70.7

-3dB (Oscilloscope BW)

3GHz Bandwidth Scope



2GHz Bandwidth Scope



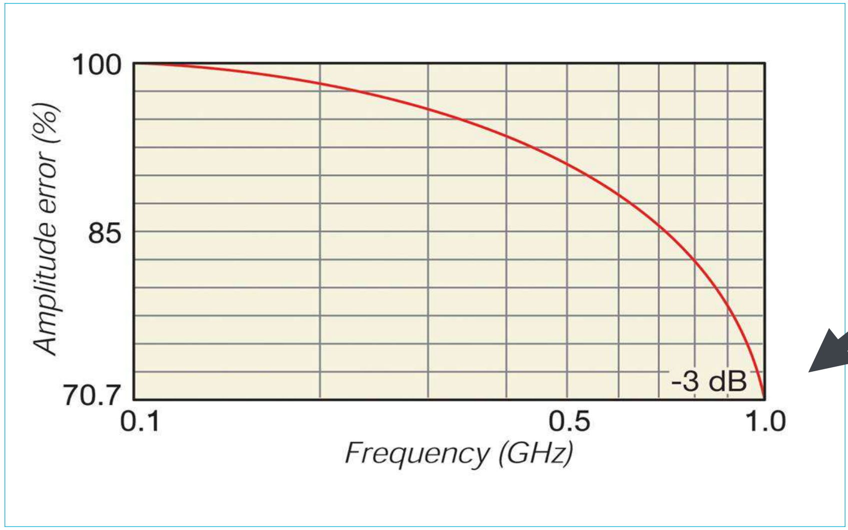
- Input Signal
  - Freq. : 2GHz
  - Amp. : 1Vpk-pk

Bandwidth

- Must have sufficient bandwidth to capture high frequency components
  - Bandwidth specified at -3 dB point

$$BW = \frac{0.35}{t_{rise}}$$

$$t_{rise} = \frac{0.35}{BW}$$



30% amplitude degradation!

At the 3dB bandwidth frequency, the vertical amplitude error will be approximately 30%.

Vertical amplitude error specification is typically 3% maximum for the oscilloscope.

When you depend on the specified maximum vertical amplitude error, divide the specified bandwidth by 3 to 5 as a rule of thumb, unless otherwise stated.

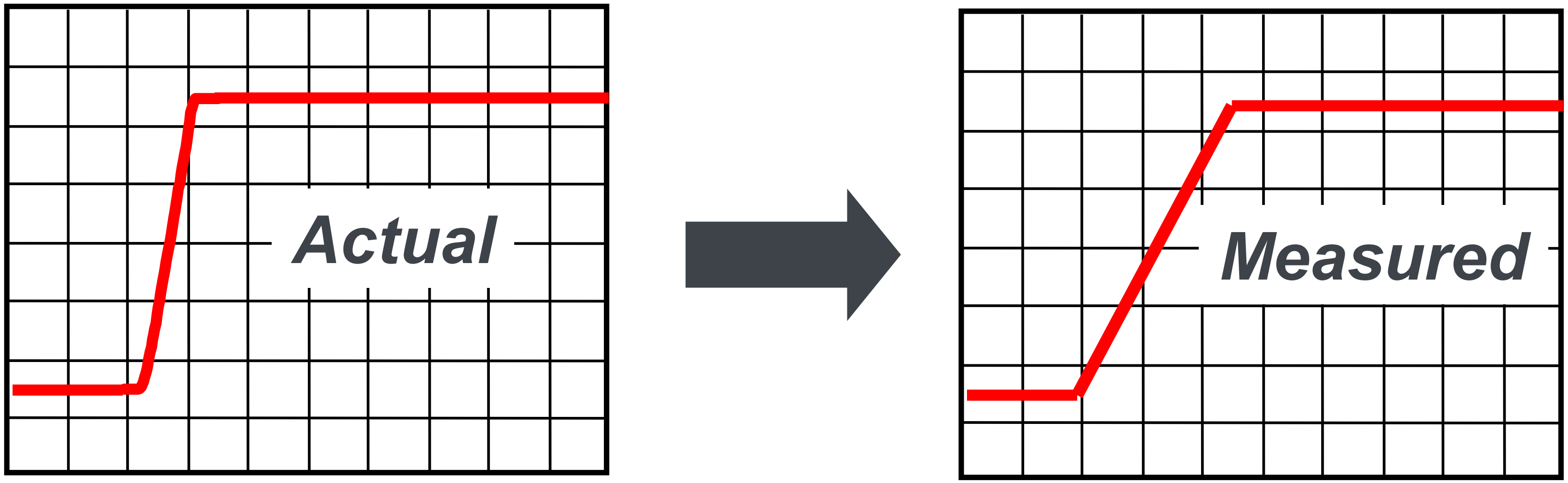
Signal Fidelity – Rise Time

- Insufficient rise time also affects the signal
- To accurately characterize your signal, follow the ***1/5th Rule***

$$T_{r,\ system} > \frac{T_{r,signal}}{5}$$

- Measured rise time depends on the signal ***and*** scope rise times

$$T_{r,Measured} = \sqrt{(T_{r,signal})^2 + (T_{r,\ system})^2}$$



Rise Time Concern

If accurate timing measurements are required, such as ...

- — **Rise or fall times**
- — **Time interval**
- — **Propagation delay**

Remember that scope rise time tr = $\frac{0.35}{BW} = \frac{0.35}{3 \times 10^{9}} = 117ps$

and

Scope Displayed tr = $\sqrt{tr_{(scope)}^2 + tr_{(DUT)}^2}$

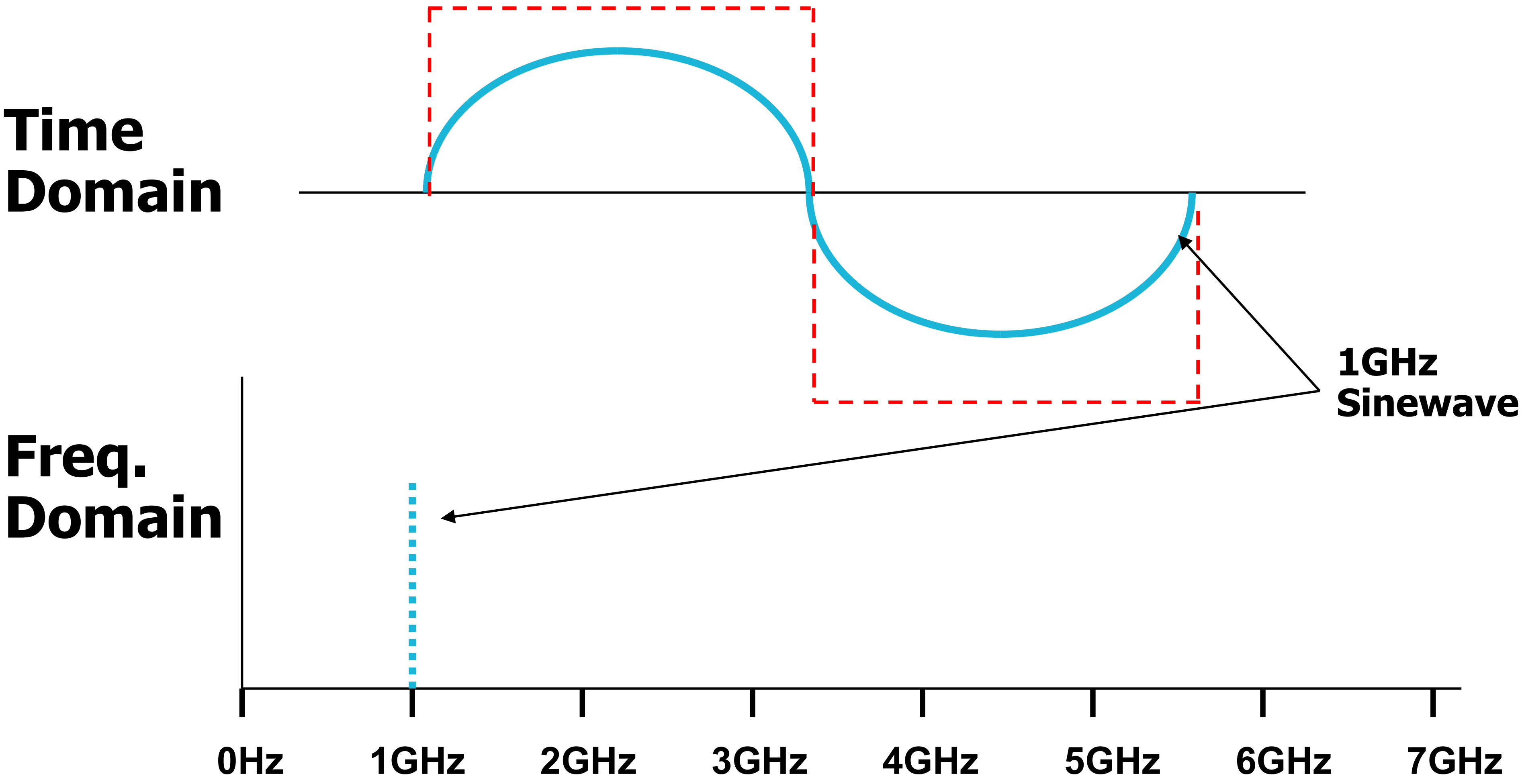
Rise Time Concern

* Device Under Test (DUT) rise time = 500ps

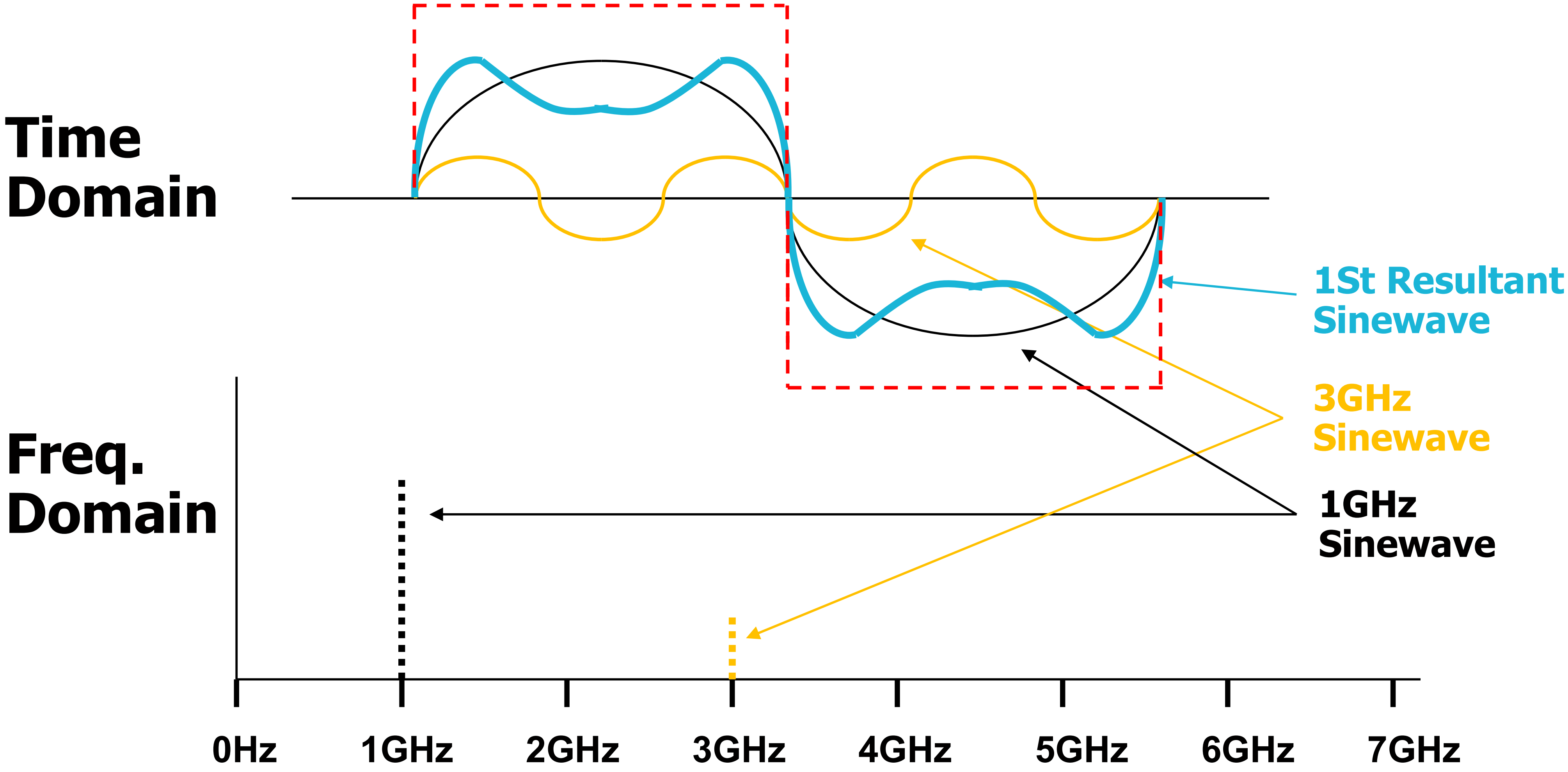
3GHz (117ps) Scope Measurement	→	***Scope Displayed tr = 513ps*** ***Resulting in a 2.5% error***
1GHz (350ps) Scope Measurement	→	***Scope Displayed tr = 610ps*** ***Resulting in a 22% error***

$$\text{Scope Displayed tr} = \sqrt{tr_{(scope)}^2 + tr_{(DUT)}^2}$$

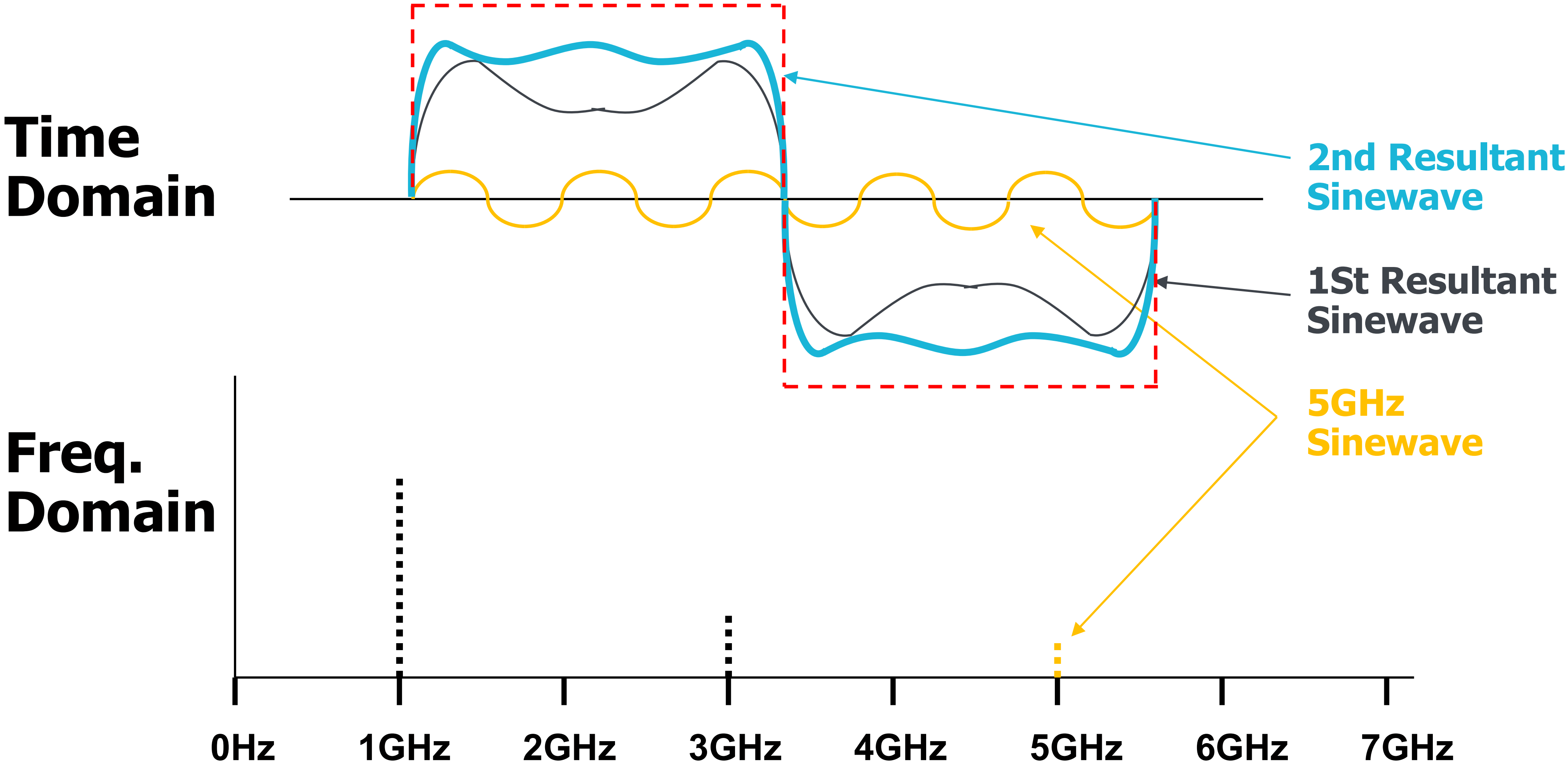
Rise Time vs. Signal Frequency



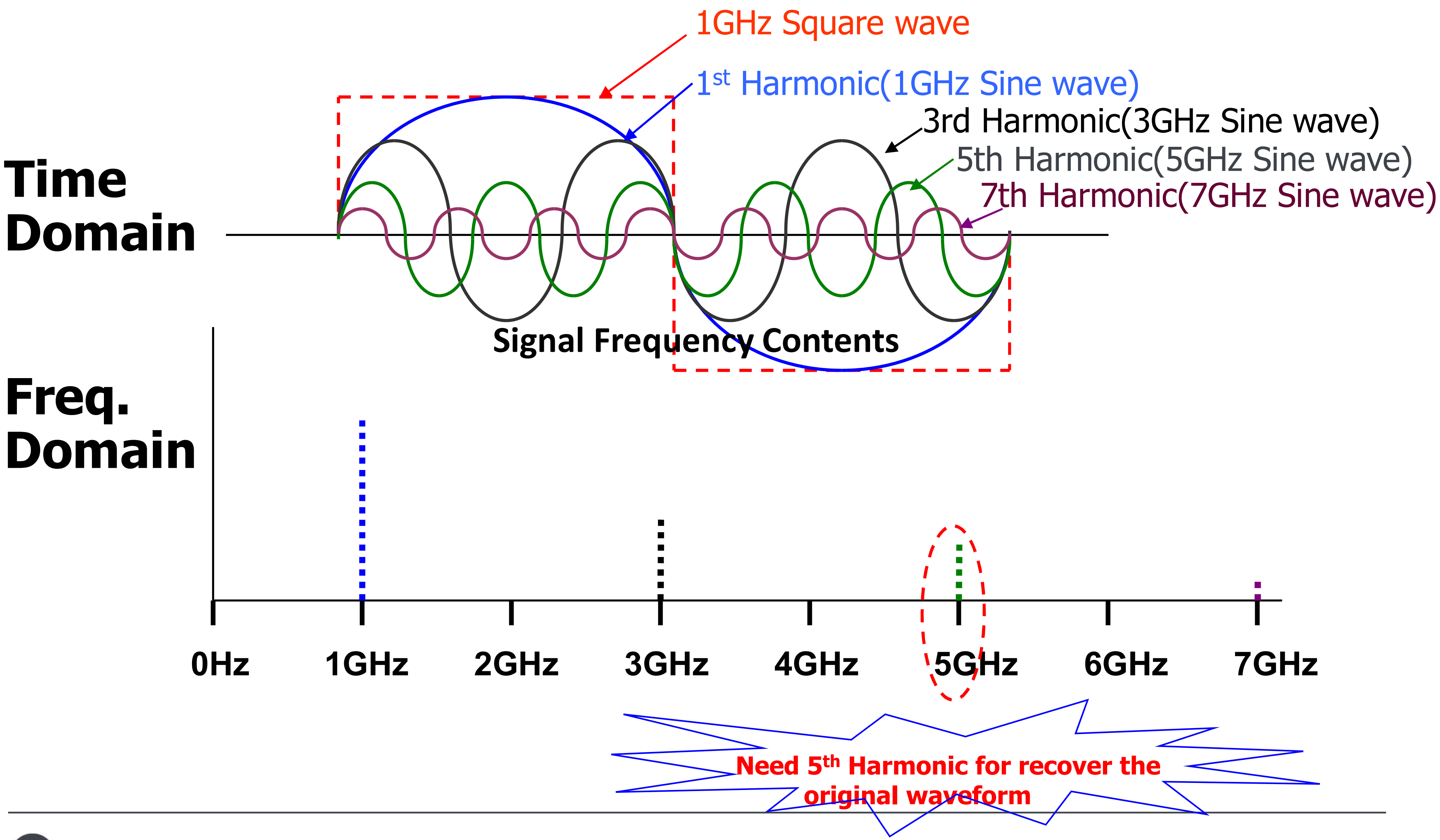
Rise Time vs. Signal Frequency



Rise Time vs. Signal Frequency



Rise Time vs. Signal Frequency



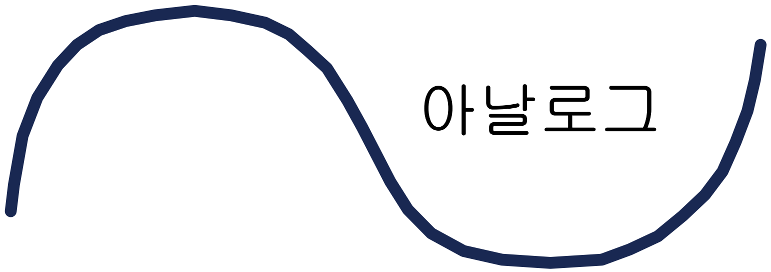
Hands-on Lab:#2

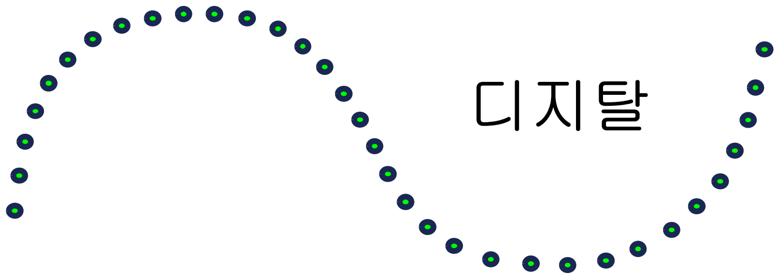
Understanding Bandwidth

Sample Rate

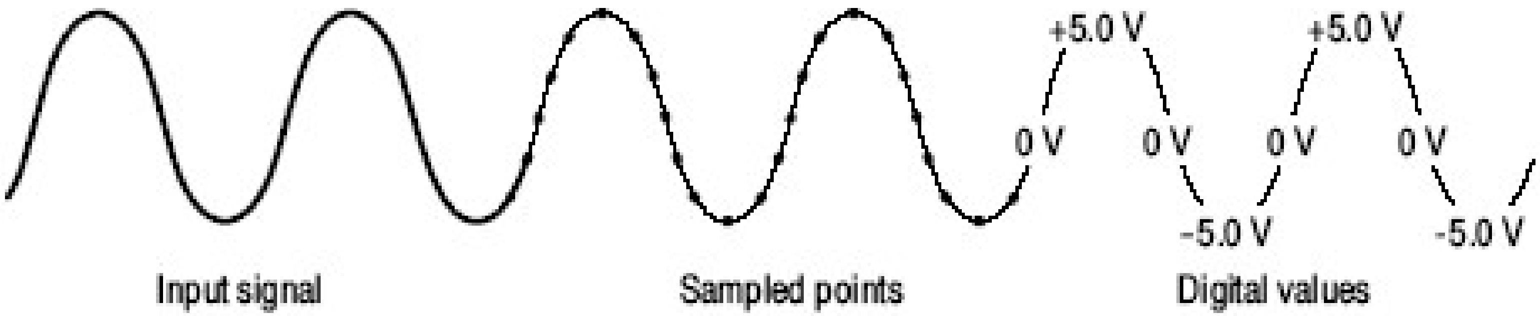
Record Length

A-D-C


아날로그

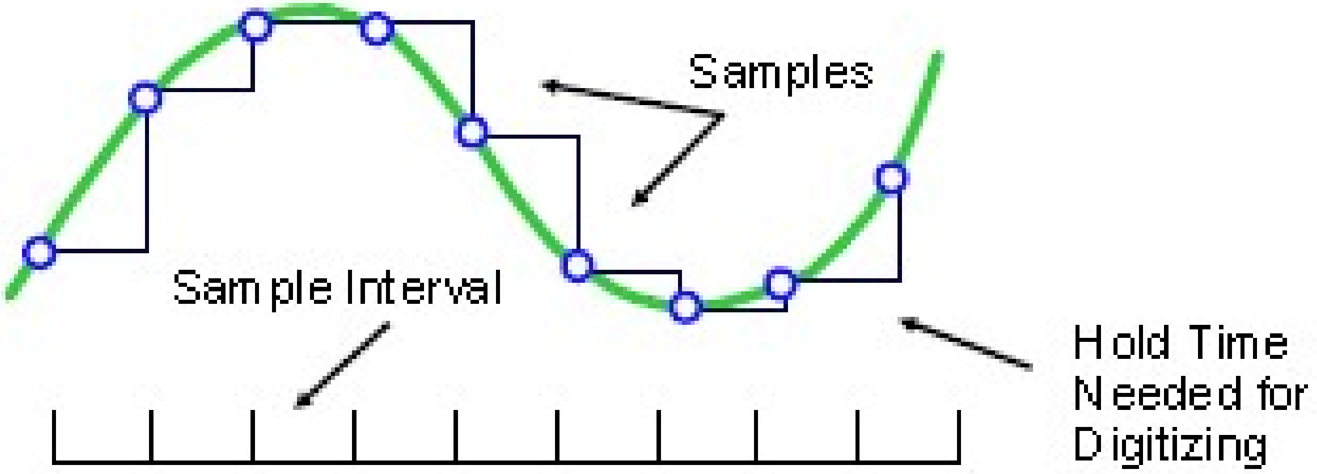

디지탈

변환


+5.0 V
+5.0 V
0 V
0 V
0 V
0 V
-5.0 V
-5.0 V
Input signal
Sampled points
Digital values

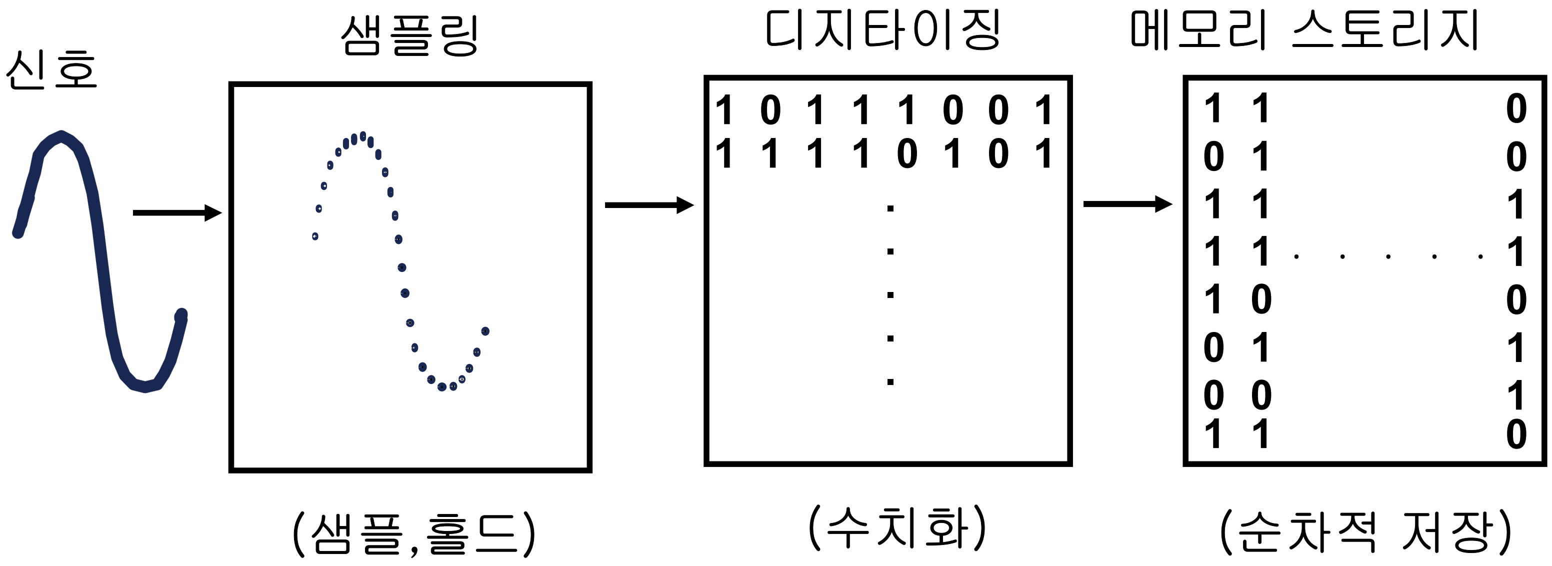
Sampling

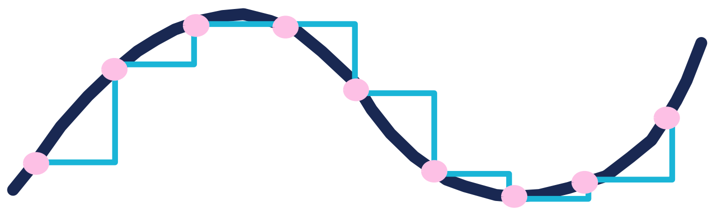
Taking Samples of an input signal at specific points in time

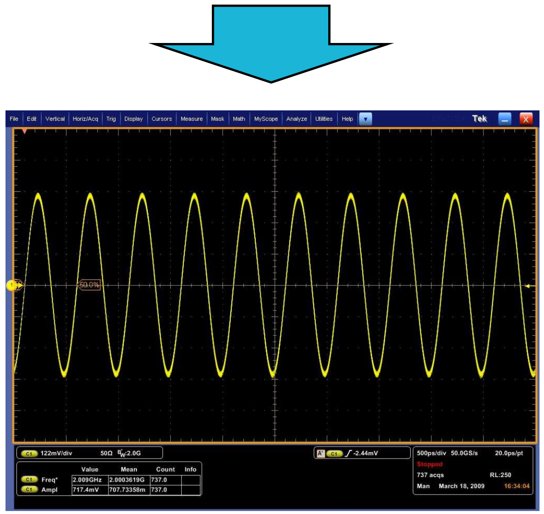


- Samples Equally Spaced in Time
- Sample Rate Measured in Sample/Second (S/s, kS/s, MS/s, GS/s)

Sampling process



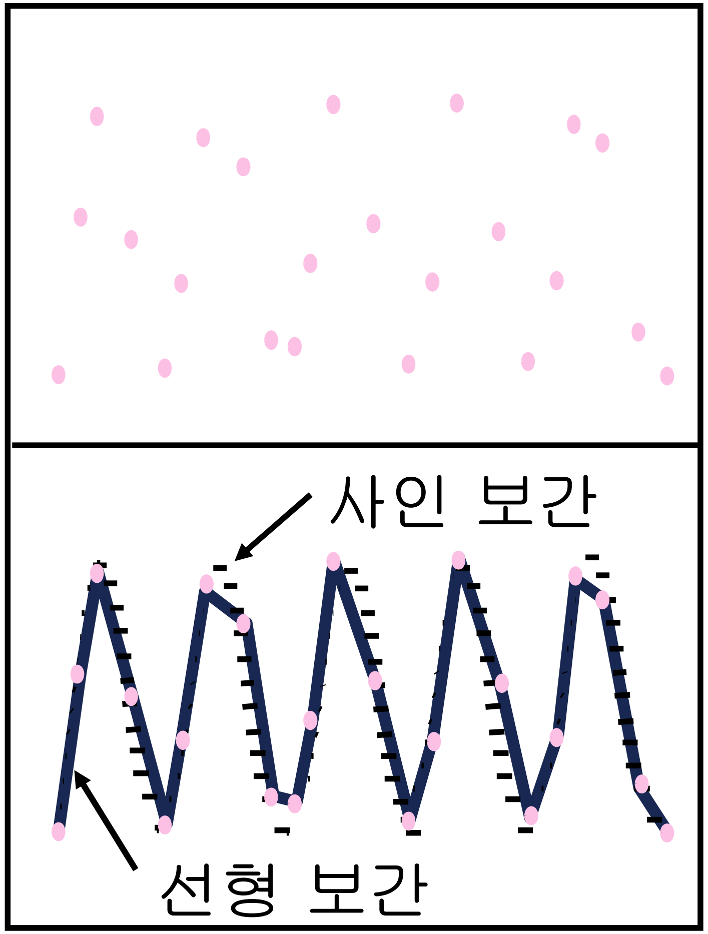




- 샘플은 시간에 대해 등간격
- 샘플 속도(SR)는 초당 샘플수로 측정 (S/s, kS/s, MS/s, GS/s)

Interpolation

- Linear Interpolation
  - 포착된 샘플들을 직선으로 연결.
  - 측정신호 주파수의 10배 샘플레이트 필요
- Sin(x)/x Interpolation
  - 샘플 데이터와 sin(x)/x 함수와의 컨볼루션 연산에 의해 포착된 샘플간의 경로를 계산한다.
  - 측정 신호 주파수의 2.5배 샘플레이트 필요



Sampling Technique

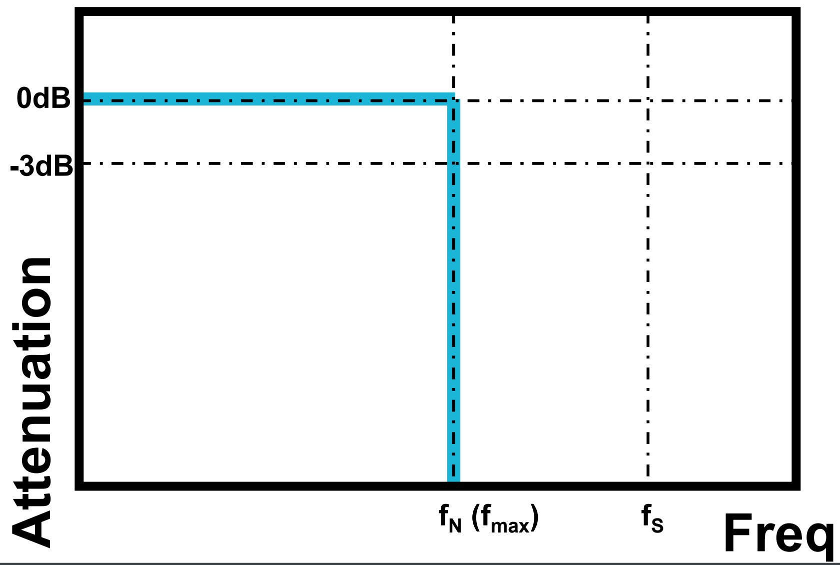
Nyquist's sampling theorem

- **Nyquist's sampling theorem** states that for a limited bandwidth (band-limited) signal with maximum frequency f_{max}, the **equally spaced sampling** frequency f_s must be greater than twice of the maximum frequency f_{max}, i.e.,

$$f_s > 2 \cdot f_{max}$$

in order to have the signal be uniquely reconstructed without aliasing.

- The frequency **2·fmax** is called the **Nyquist sampling rate (f_S)**. Half of this value, $\mathbf{f_{max}}$, is sometimes called the Nyquist frequency (f_N).



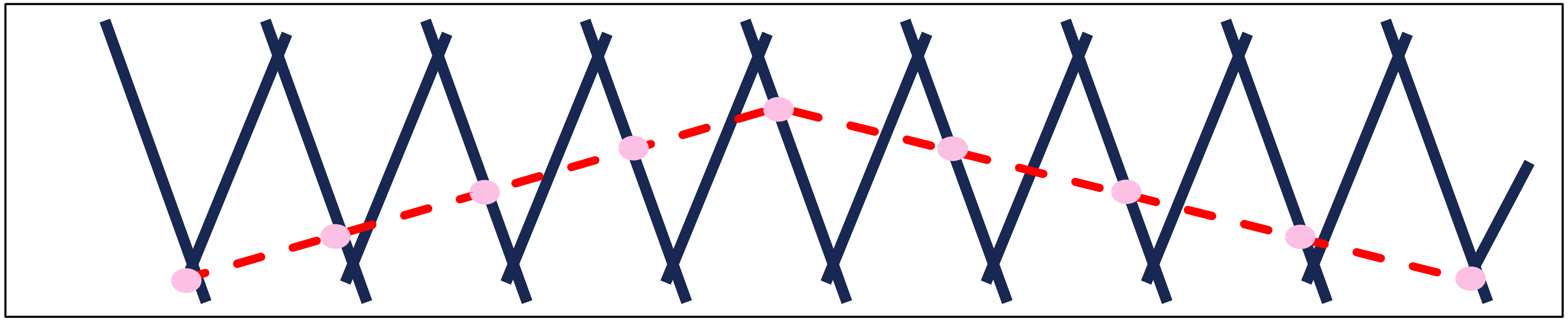
Aliasing

Nyquist’s Sampling Theory

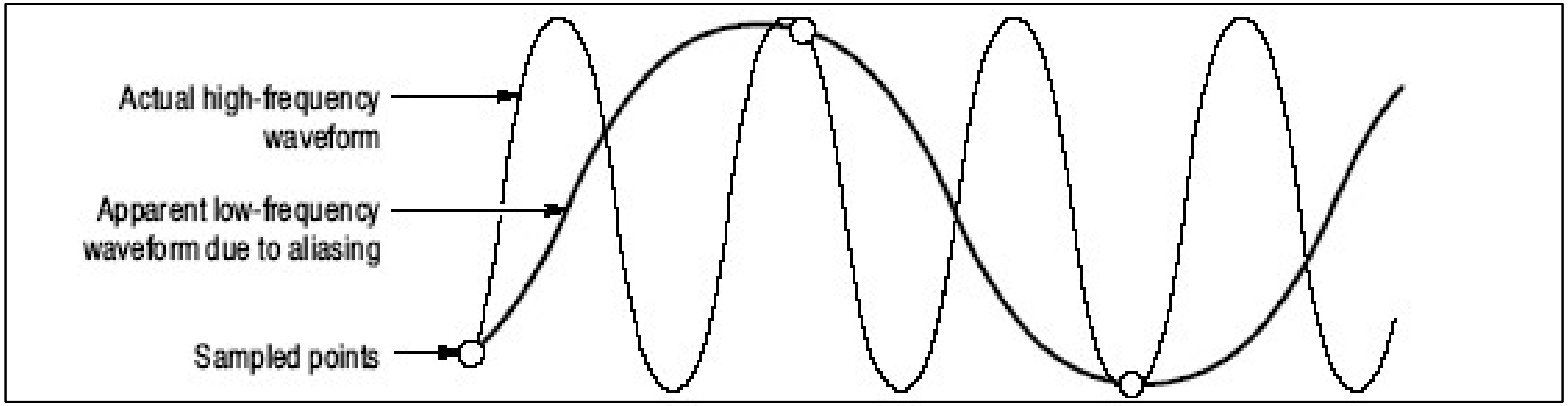
- Late 1920s Harry Nyquist, an AT&T scientist
- “For periodic functions, if you sampled at a rate that was at least twice as fast as the signal of interest, then no information (data) would be lost upon reconstruction.”
- Nyquist, Harry, "Certain topics in Telegraph Transmission Theory," published in 1928

Aliasing

- 신호에 대한 언더 샘플링에 의해 발생

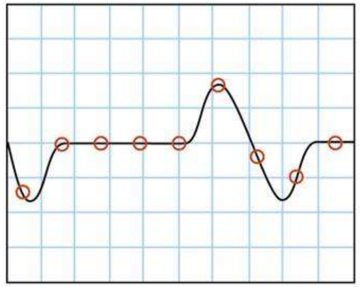


- 파형을 낮은 주파수로 재현시킨다.



Sample Rate

- Determines how frequently an oscilloscope takes a sample
  - Faster sample rate, greater resolution and waveform detail



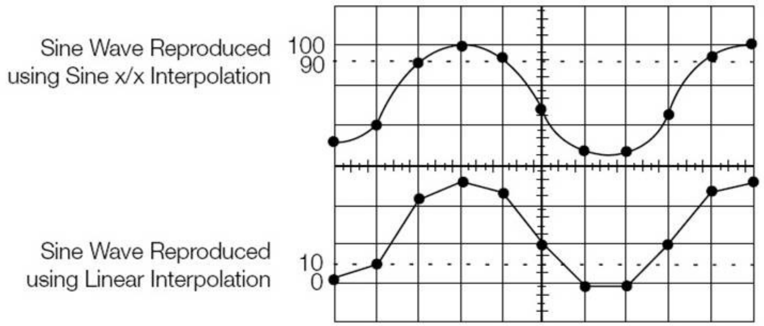
- Required Sample Rate

Sample Rate > 2.5 X $f_{Highest}$

For sin(x)/x interpolation

Sample Rate > 10 X $f_{Highest}$

For linear interpolation



Memory - Record Length

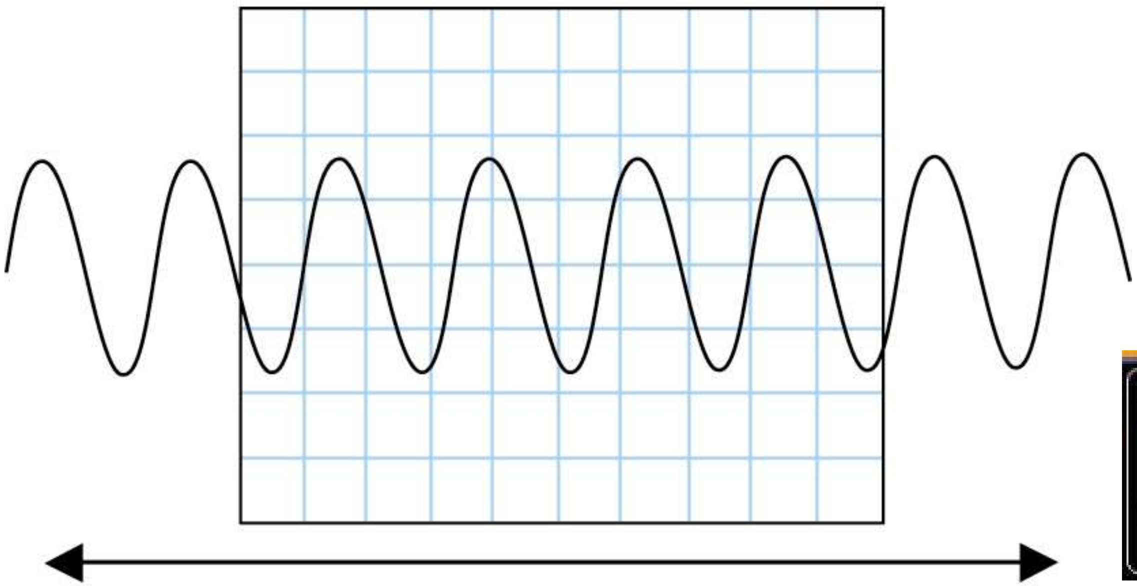
- Step

1. **Determine Required Resolution Between Samples $= T_r$**
   - **$1 / T_r \leq$ Scope Sample Rate (Real Time Sampling Mode)**

2. **Determine Required Period of Time to Capture $= T_p$**
3. **Calculate Required Memory Depth**
   - **Memory Depth $= T_p / T_r$**

Memory - Record Length

- Determines how much "time" and detail can be captured in a single acquisition
- Longer record length, longer time window with high resolution

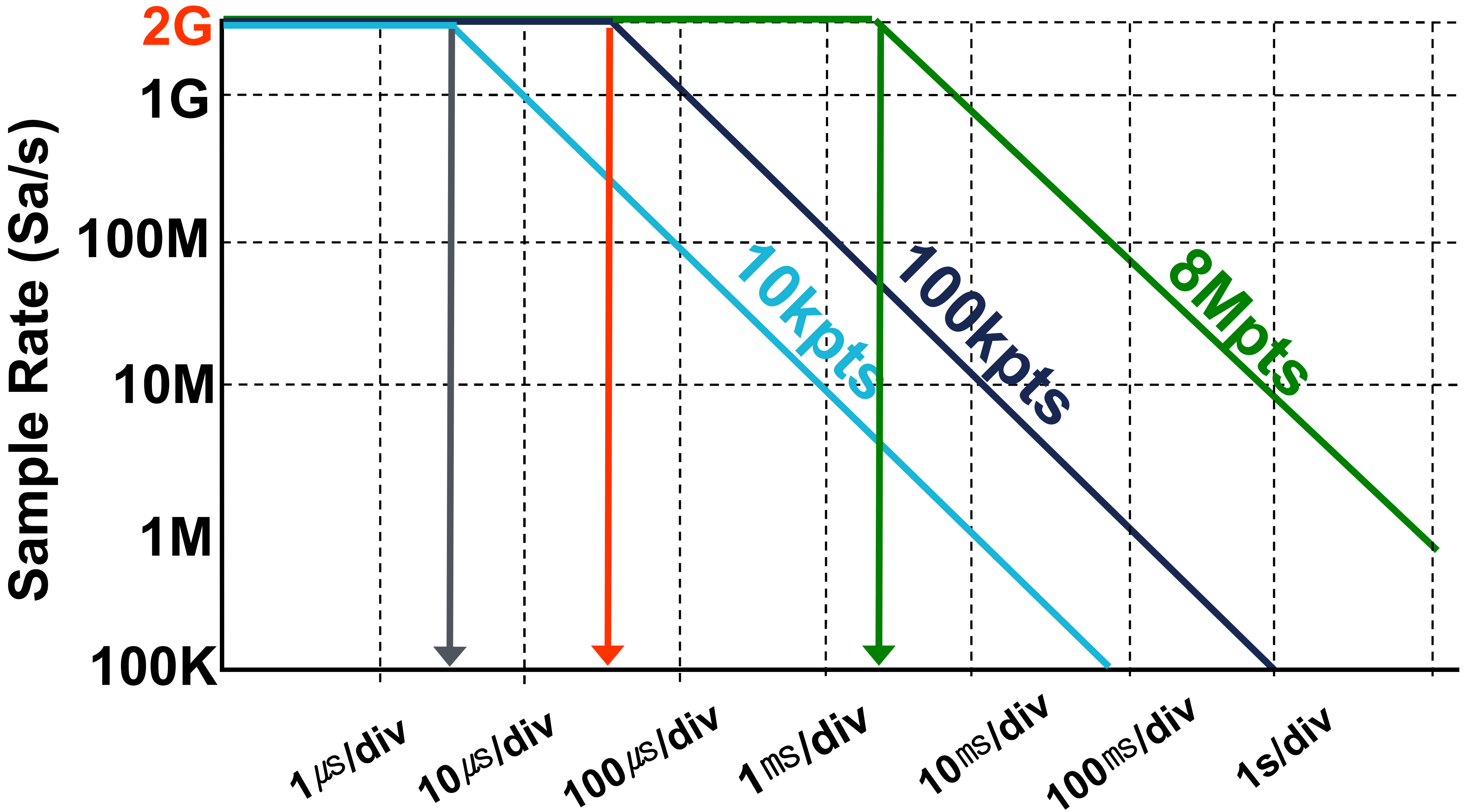


$$\text{Time} = \frac{\text{Record Length}}{\text{Sample Rate}}$$

Memory - Record Length

$$\text{Time} = \frac{\text{Record Length}}{\text{Sample Rate}}$$

Trade off between Sample rate and Record Length



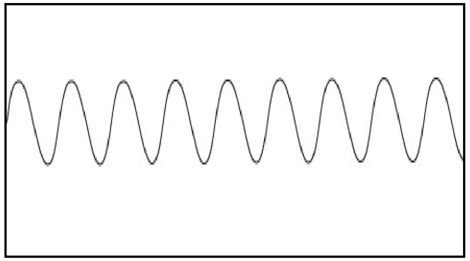
Hands-on Lab:#3

Sample rate vs. Record length
Aliasing

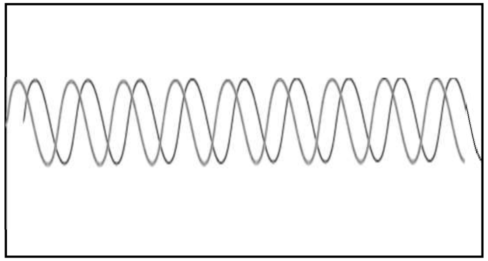
Trigger System

Trigger System and Controls

- Trigger controls allow you to stabilize repetitive waveforms and capture single-shot waveforms

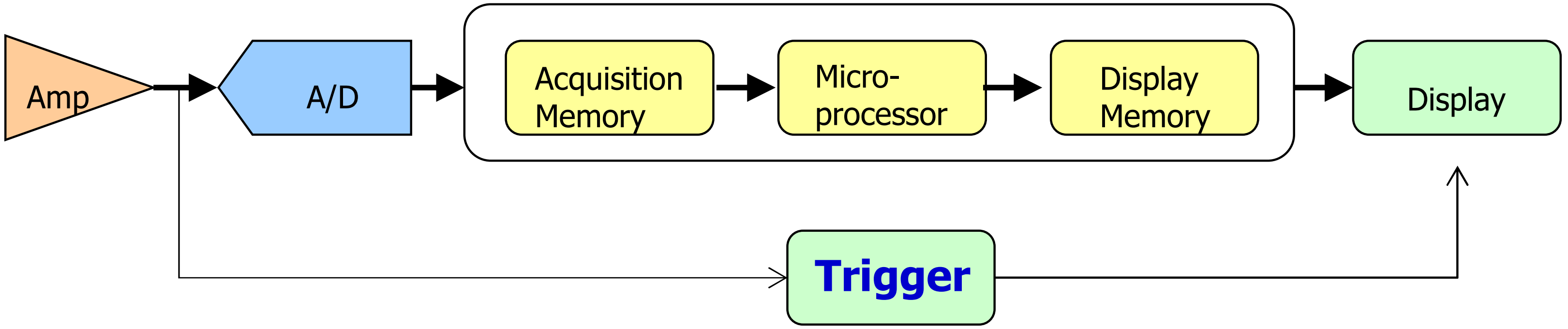


Triggered Display
(Normal Mode)



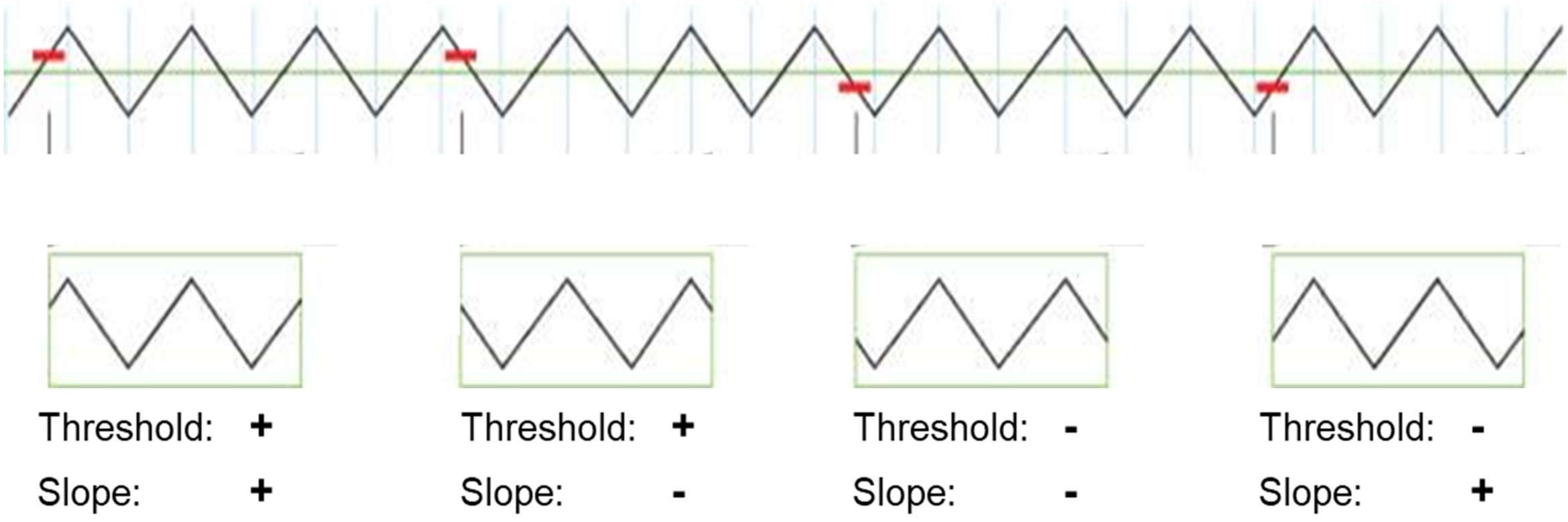
Untriggered Display
(Auto Mode)

- **Trigger Modes**
  - **Normal mode**: scope only sweeps if input signal reaches trigger point.
  - **Auto mode**: scope sweeps, even without a trigger, based on a timer.
  - **Single-sequence mode**: after trigger is detected, scope acquires and displays one record length of the signal.

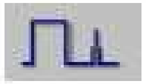
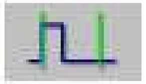
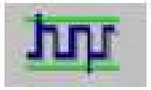


Trigger Level and Slope

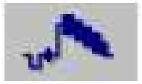
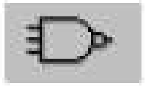
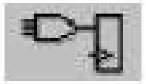
- Slope control determines if the trigger point is the rising edge or falling edge of the signal
- Level control determines where on the edge the trigger point occurs



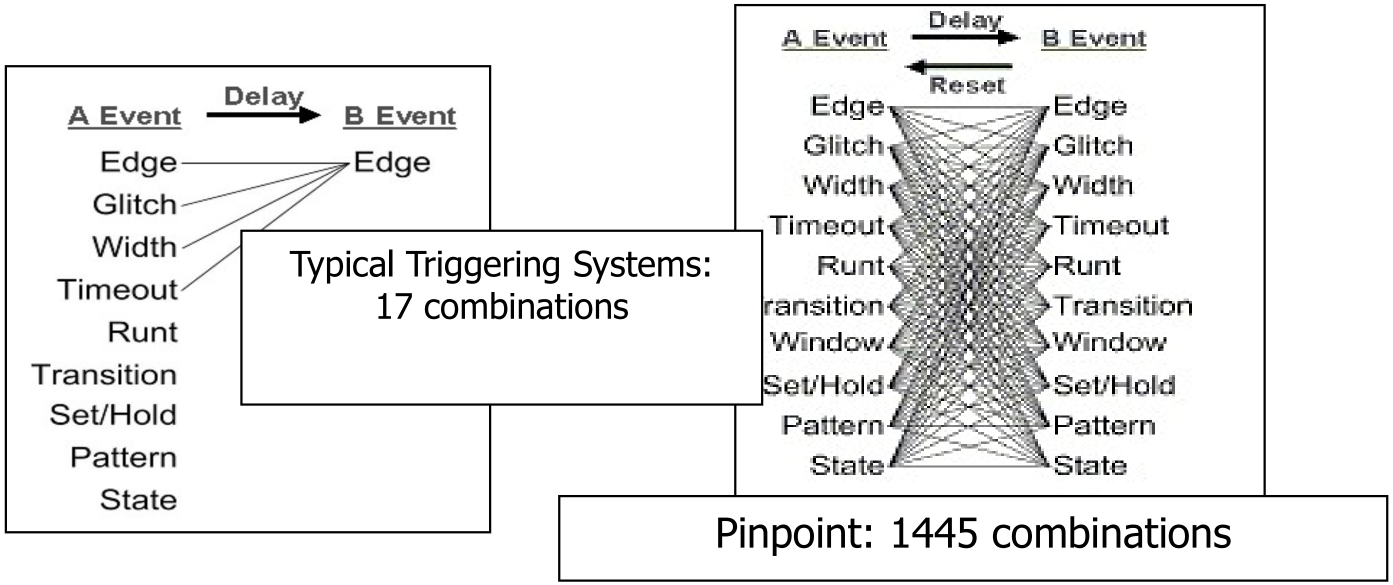
오실로스코프 트리거 종류 및 기능

Edge		Trigger on a rising or falling edge, as defined by the slope control. Coupling choices are DC, AC, LF Reject, HF Reject, and Noise Reject.
Glitch		Trigger on a pulse narrower (or wider) than the specified width or ignore glitches narrower (or wider) than the specified width.
Width		Trigger on pulses that are inside or outside a specified time range. Can trigger on positive or negative pulses.
Runt		Trigger on a pulse amplitude that crosses one threshold but fails to cross a second threshold before recrossing the first. Can detect positive or negative runts, or only those wider than a specified width. These pulses can also be qualified by the logical state of other channels (four-channel models only).
Window		Trigger when the input signal rises above an upper threshold level or falls below a lower threshold level. Trigger the instrument as the signal is entering or leaving the threshold window. Qualify the trigger event in terms of time by using the Trigger When Wider option, or by the logical state of other channels using the Trigger When Logic option (four-channel models only).
Timeout		Trigger when no pulse is detected within a specified time.
Transition		Trigger on pulse edges that traverse between two thresholds at faster or slower rates than the specified time. The pulse edges can be positive or negative.

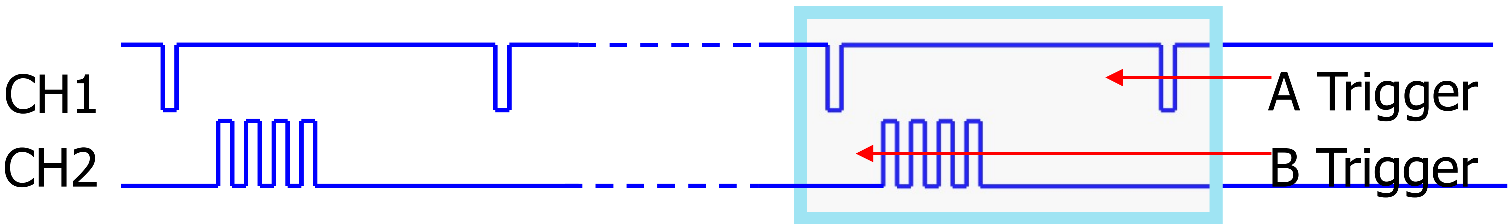
오실로스코프 트리거 종류 및 기능

Video		Trigger on specified fields or lines of a composite video signal. Only composite signal formats are supported.
Pattern		Trigger when logic inputs cause the selected function to become True or False. You can also specify that the logic conditions must be satisfied for a specific amount of time before triggering.
State		Trigger when all of the logic inputs to the selected logic function cause the function to be True or False when the clock input changes state.
Setup/ Hold		Trigger when a logic input changes state inside of the setup and hold times relative to the clock.
Comm		Trigger in conjunction with mask testing on communications codes and standards. The controls work together to define the parameters for the trigger event.

Extended *Pinpoint* Trigger System



- Use Pin-Point Trigger
  - A Trigger and B Trigger



* Pinpoint trigger is supported Windows OS based Oscilloscope models

Hands-on Lab:#4

Trigger System

1. Trigger Type : Runt
2. Trigger Setup
   - Upper Level : 2.0V
   - Lower Level : 800mV

1. Trigger Type : Width
2. Trigger Setup
   - Level : 1.5V
   - Upper Limit : 250ns
   - Low Limit : 150ns
   - Low polarity
   - Inside range

Hands-on Lab:#5

I2C validation

1. I2C probing

2. I2C Bus decoding

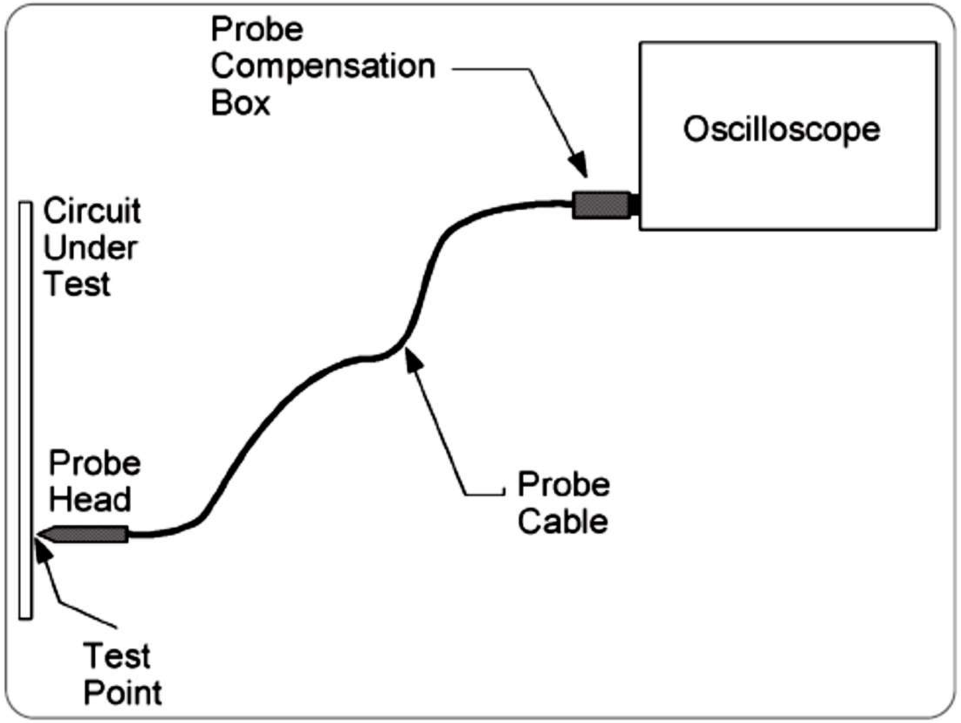
3. I2C trigger: Hex50

4. Result

Probes

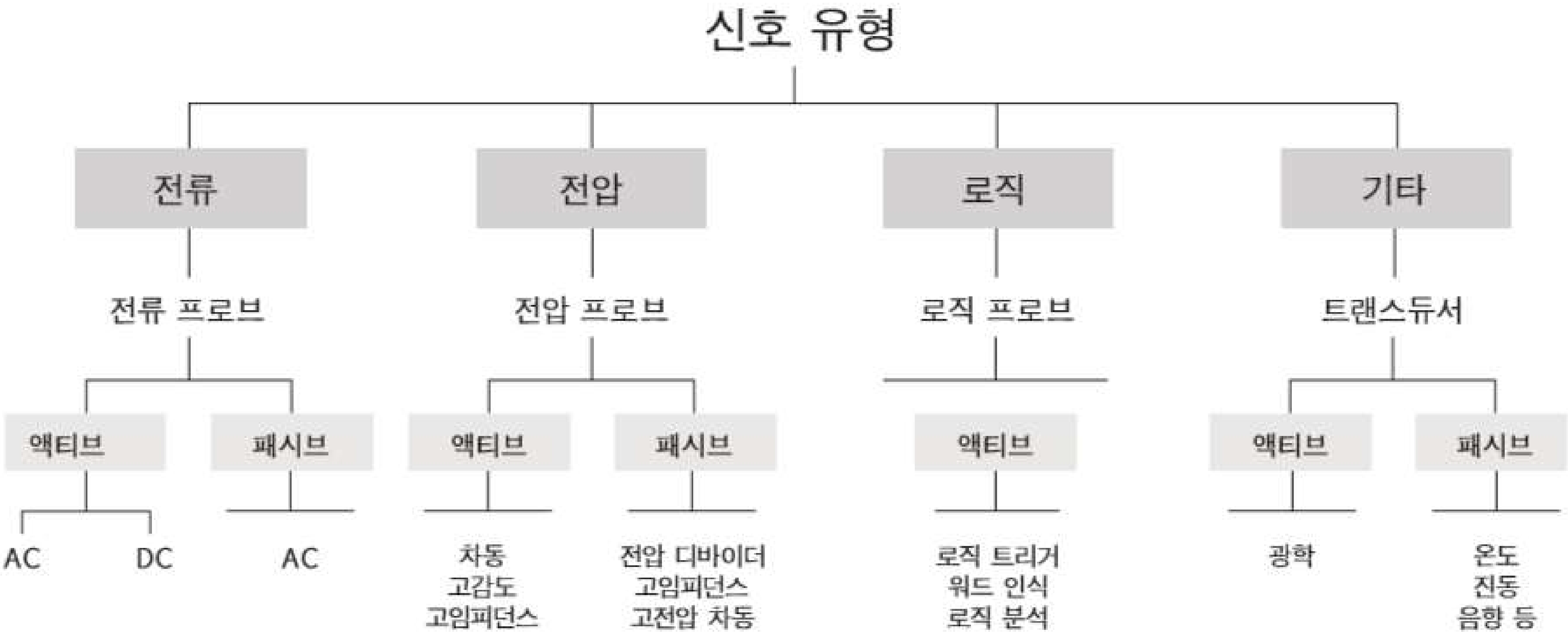
Probes

- Vital to your measurement
- Connects your DUT to your oscilloscope
- Affects measurement quality

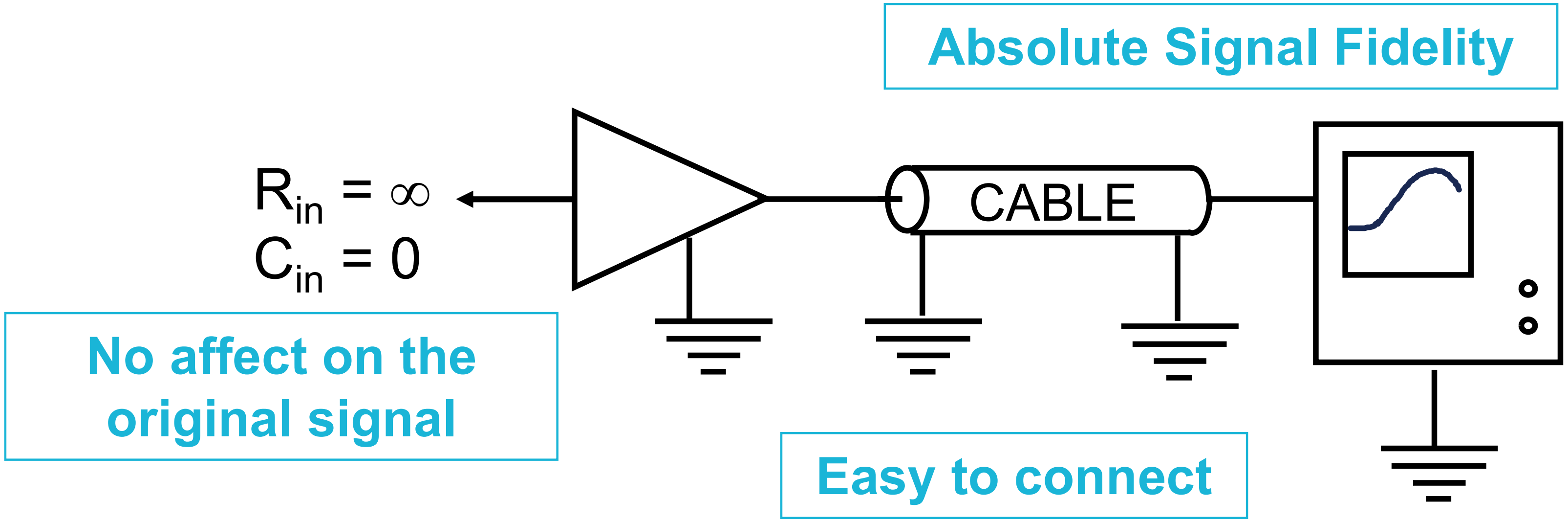


Probes

Probe Types



The Ideal Probe



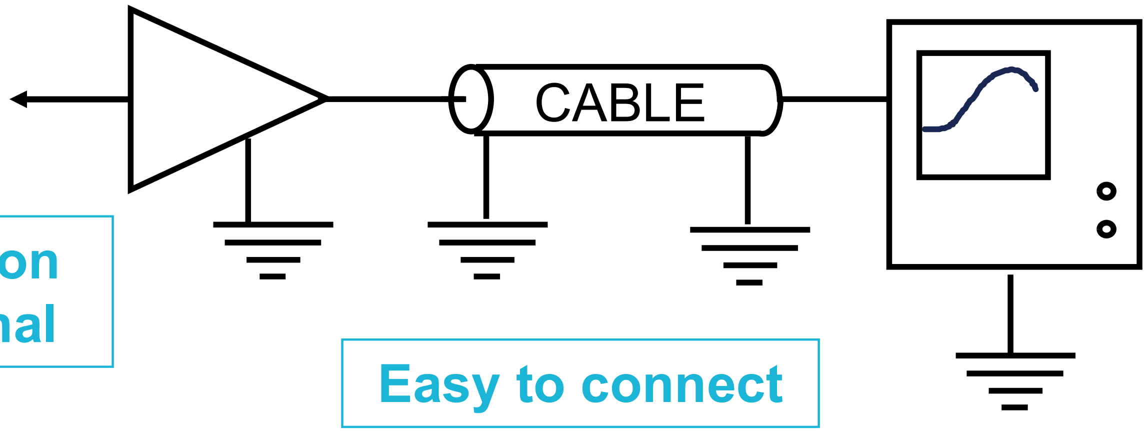
- **No affect on the original signal – *No signal source loading!***
  - Zero Input Capacitance
  - Infinite Input Resistance
- **Absolute Signal Fidelity**
  - Unlimited bandwidth
  - Unlimited rise time
  - Zero attenuation
  - Linear phase across all frequencies
- **A convenient and easy way to connect to the device-under-test**
  - Mechanically well suited to application

Probes Will Affect Your Measurement

- Signal Source Loading
  - Measurement system's impedance is critical
    - Input Resistance
    - Input Capacitance
    - Inductance

- Signal Fidelity
  - Measurement system parameters also crucial
    - Bandwidth
    - Rise Time

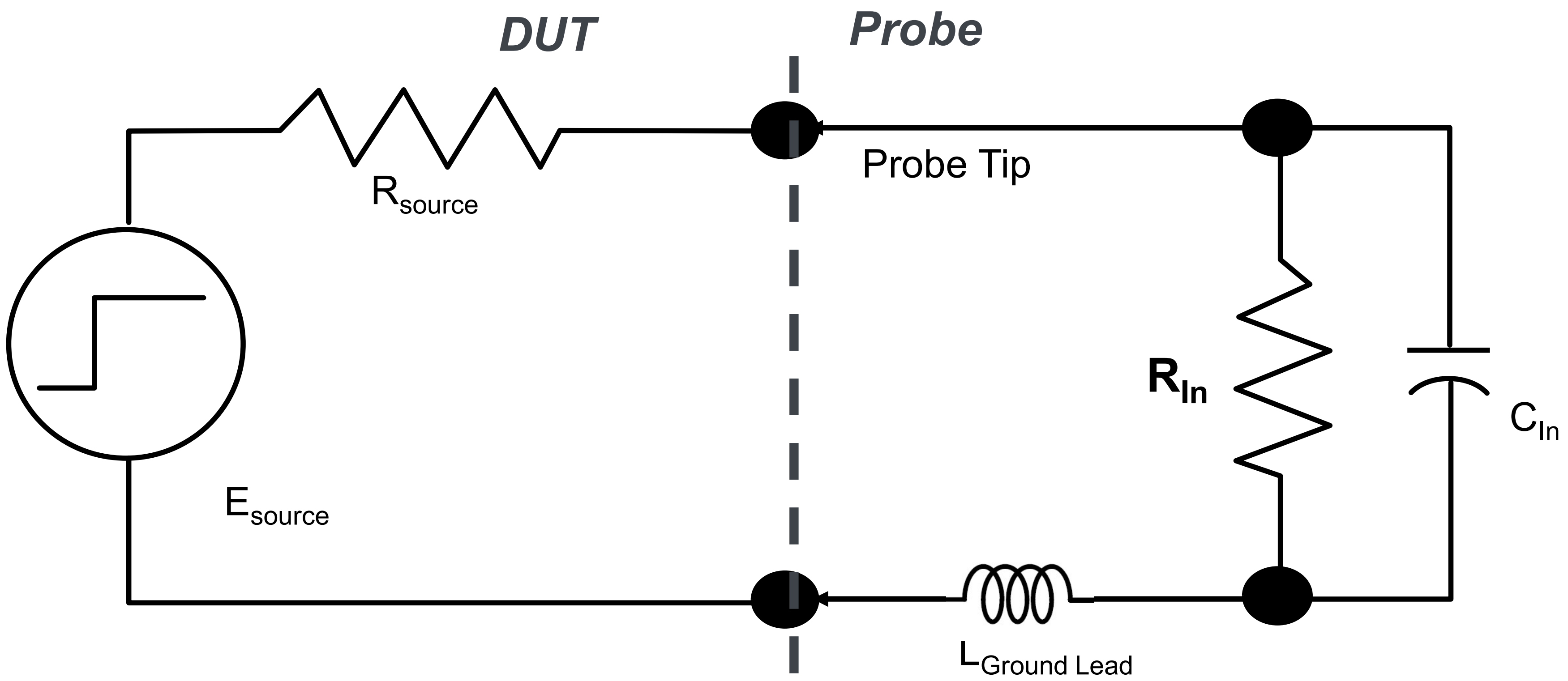
Good Signal Fidelity



Minimize affect on the original signal

Easy to connect

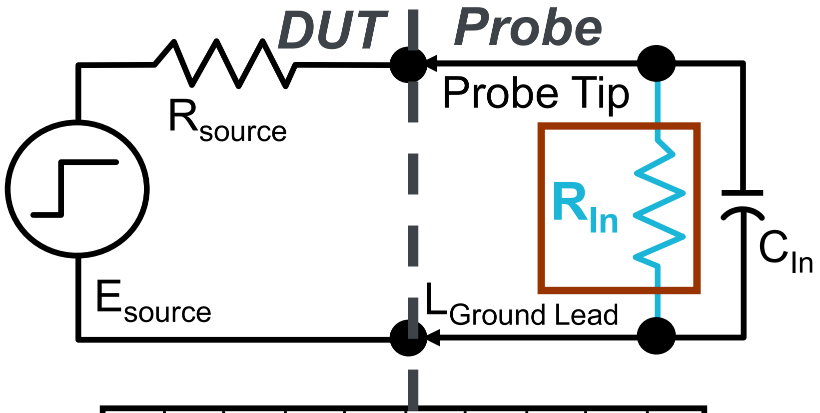
Probe Loading Effect



- **the probe will always load the device that you are testing**
  - Resistive
  - Capacitive
  - Inductive

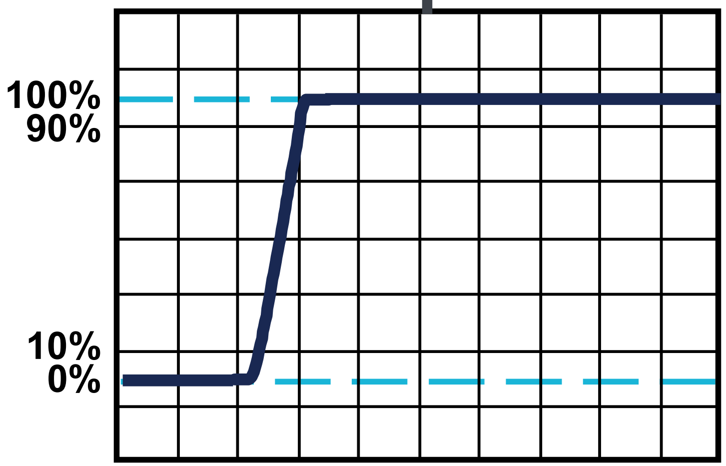
Source Loading – Input Resistance

- R_{in} acts like a voltage divider
- Higher input resistance – less loading
- Lower source resistance – less loading

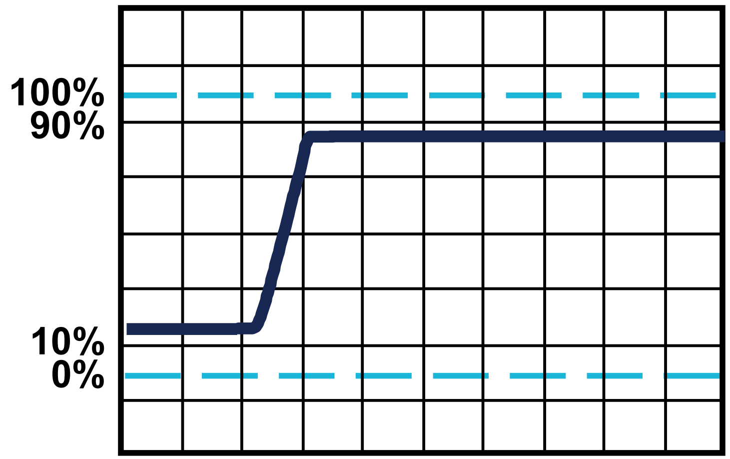


Decreased Signal Amplitude

$$V_{meas} = V_{source} \frac{R_{in}}{R_{in} + R_{source}}$$



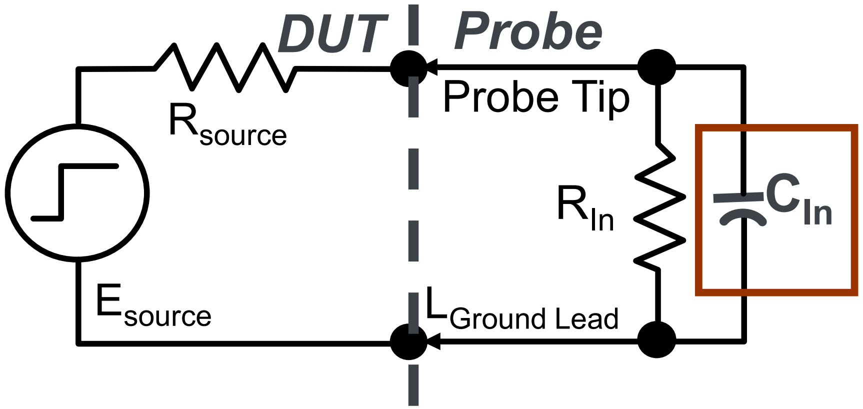
Source Signal



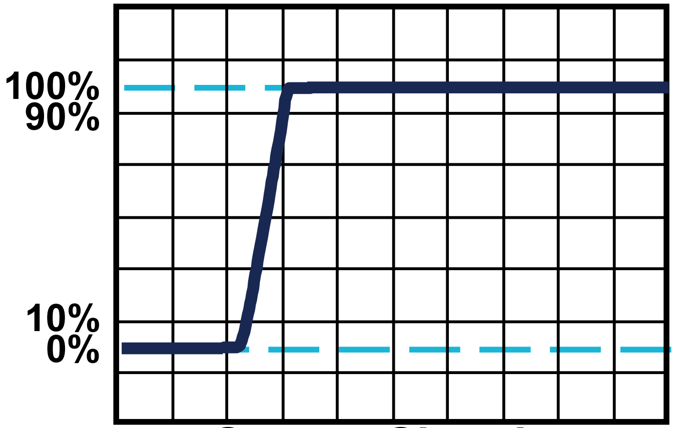
Effects of Input Resistance

Source Loading – Input Capacitance

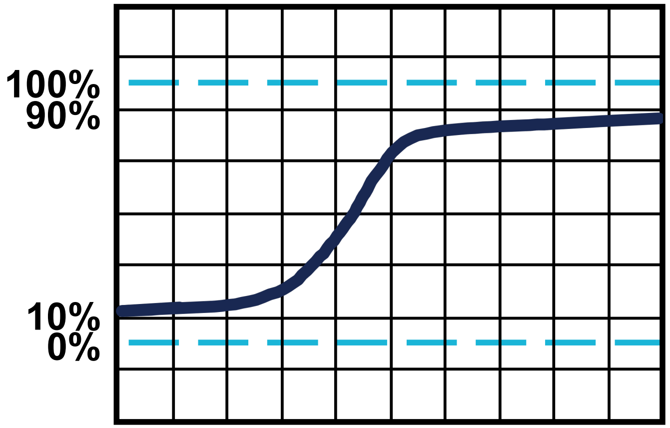
- Smaller input capacitance - higher probe impedance, less loading
- As signal frequency increases, capacitance increases and loading increases



•Decreased Amplitude
•Phase Change
•Slower Rise Time
$t_r \approx 2.2(R_{source} \times C_{in})$



Source Signal



Effects of Input Capacitance

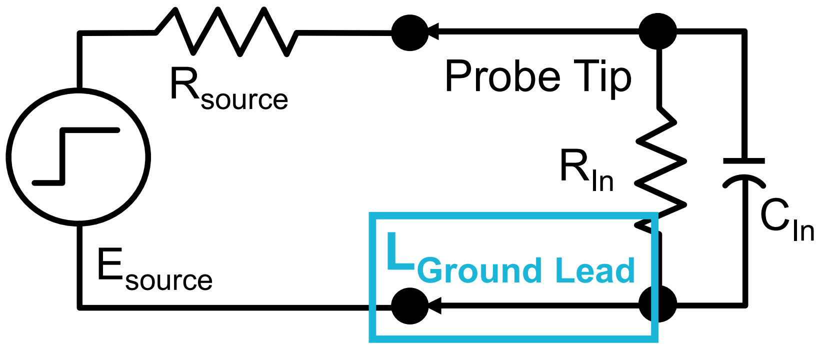
<u>Example:</u>
C_{in} = 100 pF
t_r ~ 220 nsec

C_{in} = 10pF
t_r ~ 22 nsec

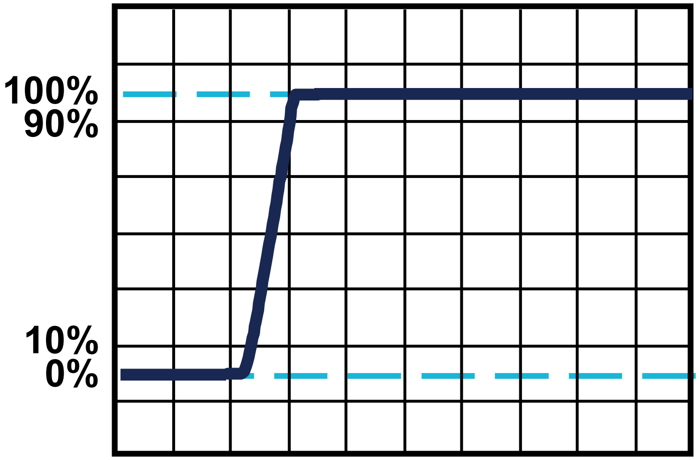
If R_{source} = 1 kΩ

Source Loading - Inductance

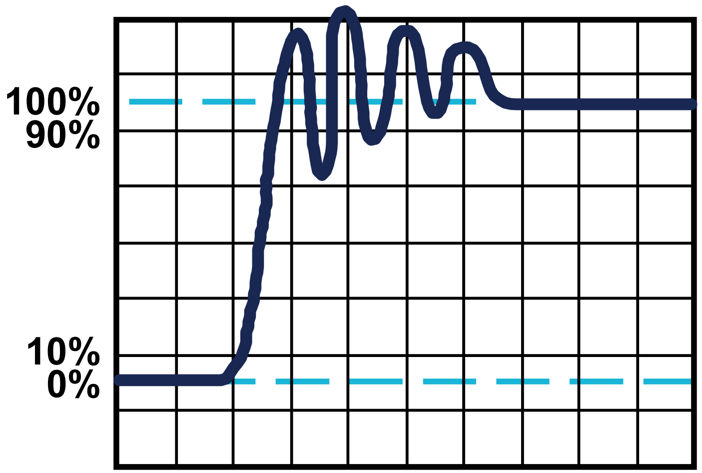
- The longer the ground lead, the higher the probe inductance.
- Keep ground leads as short as possible to avoid ringing!



Resonance (Ringing)



Source Signal

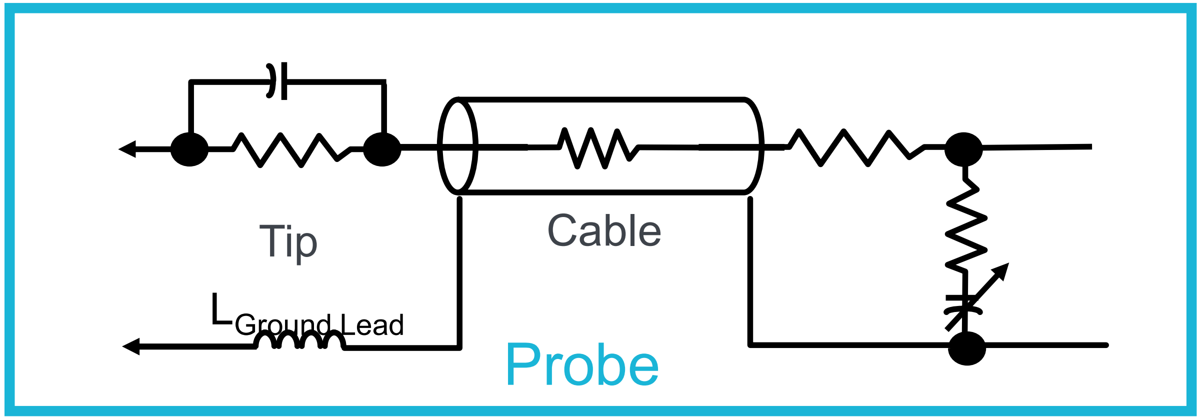


Effects of Inductance

Passive Voltage Probes

- Most basic probe with no active components
- Available in 1X, 2X, 10X, 100X and switchable
- Advantages
  - Inexpensive
  - Mechanically Rugged
  - Wide Dynamic Range
  - High Input R
- Disadvantages
  - High Input C

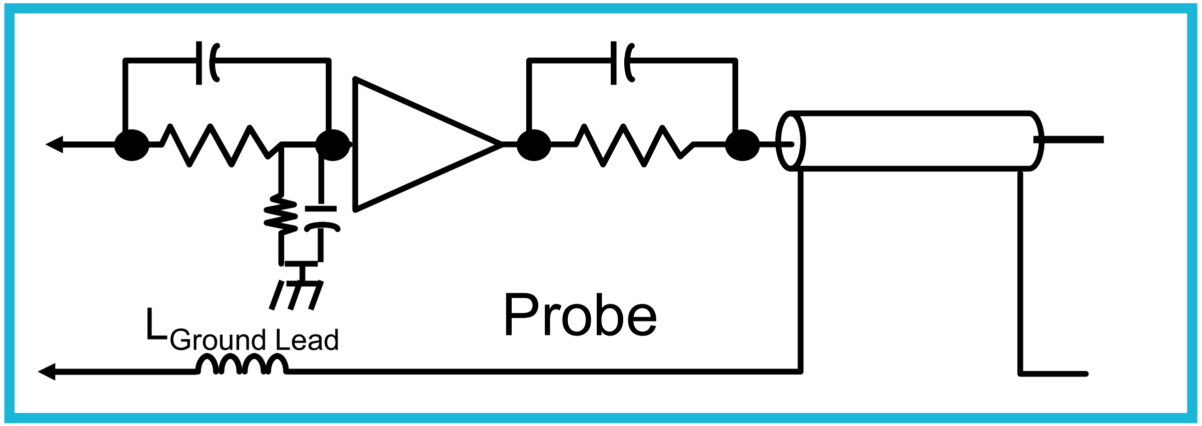
Tektronix TPP1000 Probe
*1/10X, **1GHz***



Active Voltage Probes: Single-Ended

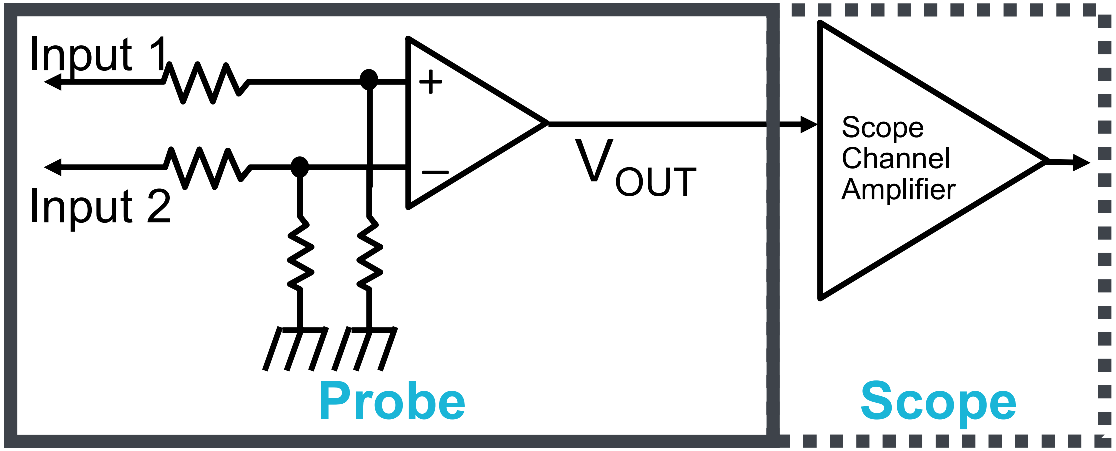
- Uses active components
- Advantages
  - Low Input C
  - Wide Bandwidth
  - High Input R
  - Better Signal Fidelity
- Disadvantages
  - Higher Cost
  - Limited Dynamic Range
  - Mechanically Less Rugged

Tektronix TAP1500
Active Voltage Probe
10X, 1.5 GHz



Active Voltage Probes: Differential

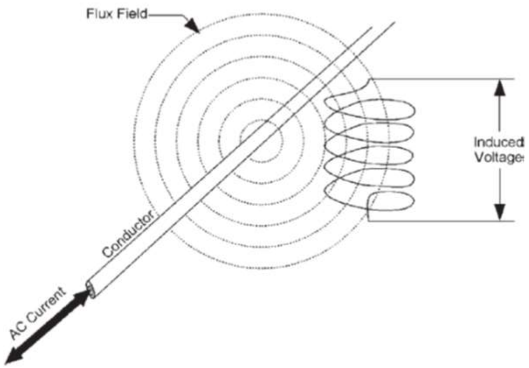
- Differential Probes measure signals that are referenced to each other instead of earth ground.
- Advantages
  - Wide bandwidth
  - Large Common Mode Rejection Ratio (CMRR)
  - Minimal skew between inputs
  - Small input capacitance



Tektronix P7700 Series TriMode Differential Probe

Current Probes

- Measures the electromagnetic flux field around a conductor to determine the current flow
- Two Major Types:
  - AC current probes (passive)
  - AD/DC current probes (active)
- Features to Consider:
  - Automatic scaling and units
  - Split-core vs. fixed-core connection to the device



Tektronix TCP0150
AC/DC Current Probe
150 A, DC to 20 MHz

Tektronix Probe Connectors and Adapters

- *TEKPROBE Level 1 BNC Probes*

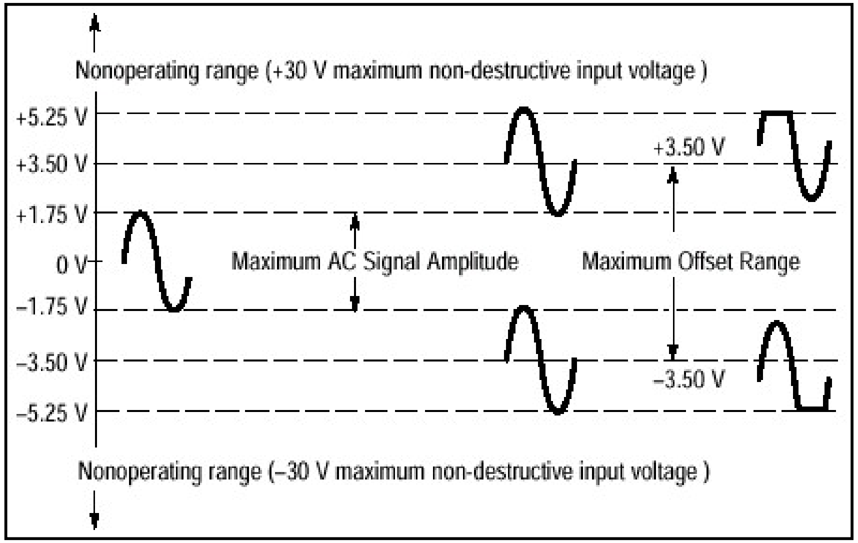
- *TEKPROBE Level 2 BNC Probes*

- *TekVPI Probes*
  TekVPI probe connection is

- *TekConnect Probes*
  Probes with our TekConnect

Voltage Window, Dynamic Range & Offset

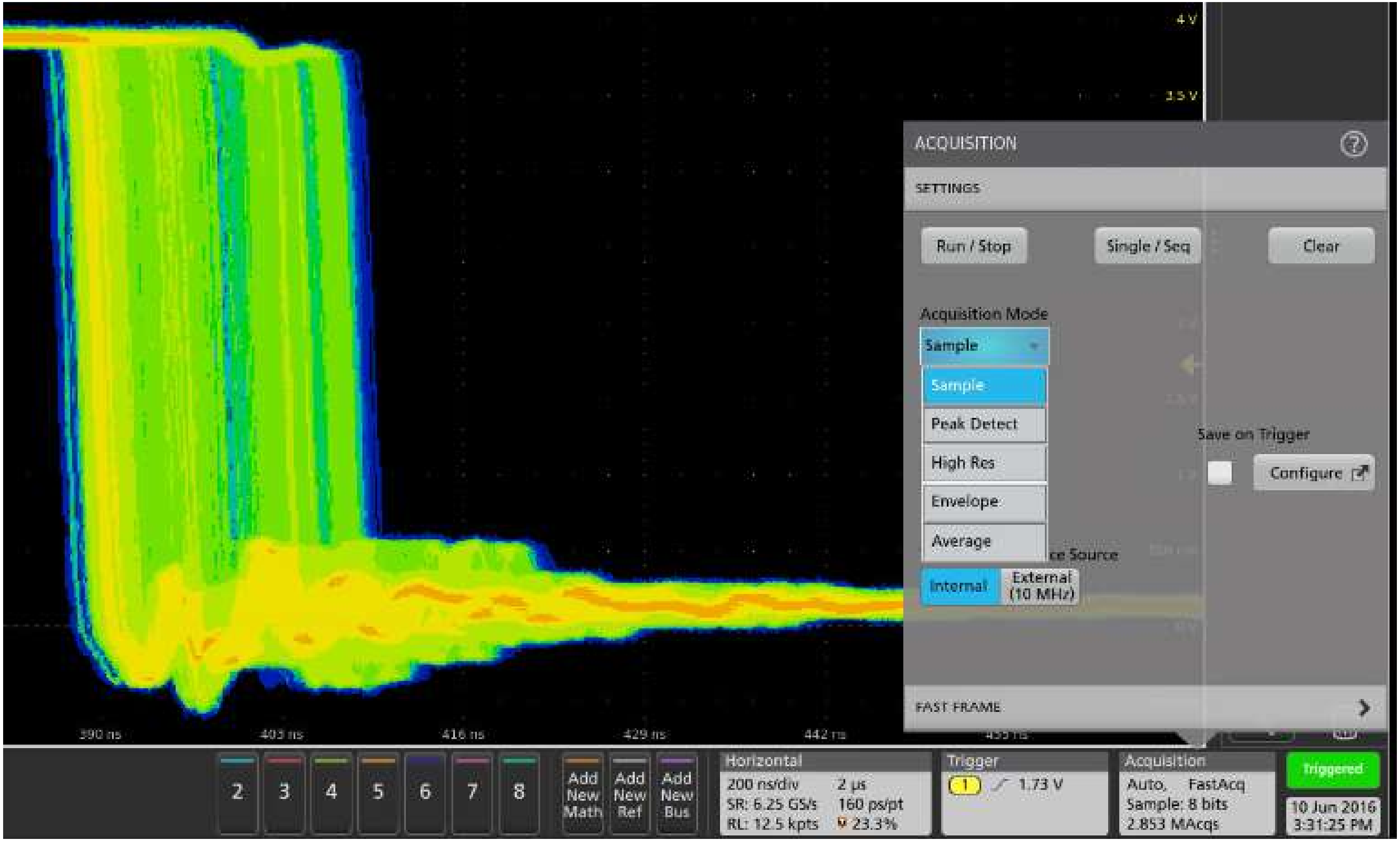
- Operating Voltage Window
  - Maximum voltage applied without Saturation
  - Incorrect Voltage Window Produces Measurement Errors
- Dynamic Range
  - Newer active probes designed around lower voltage level
  - Multiple D.R Select with trade off noise
- DC Offset
  - Positioning Of The Signal to the Center Of The D.R



Advanced Features

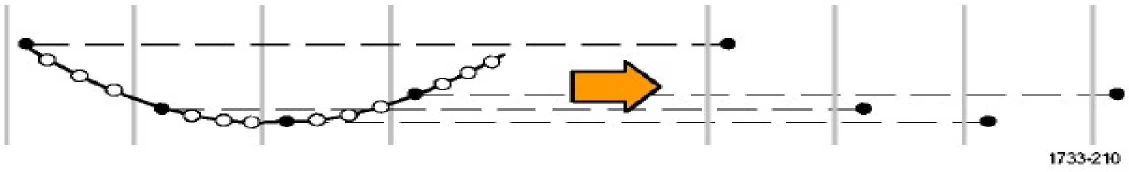
- Hori/Acq – Acquisition setup
- Hori/Acq – Acquisition Mode
- Measurement

Hori/Acq - Acquisition Setup

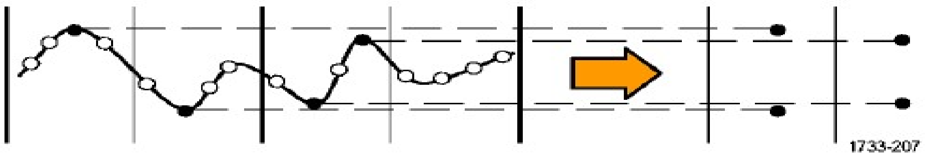


Hori/Acq - Aquisition Mode

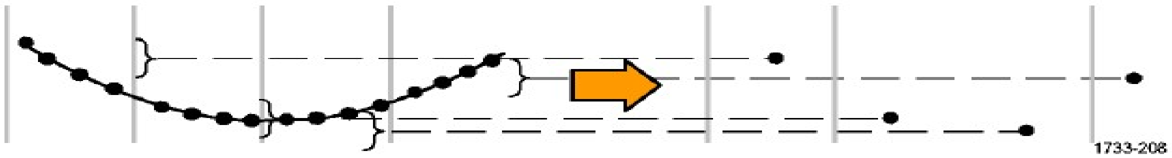
샘플 모드는 각 획득 간격에서 첫 번째 샘플링된 포인트를 유지합니다. 샘플은 기본 모드입니다.



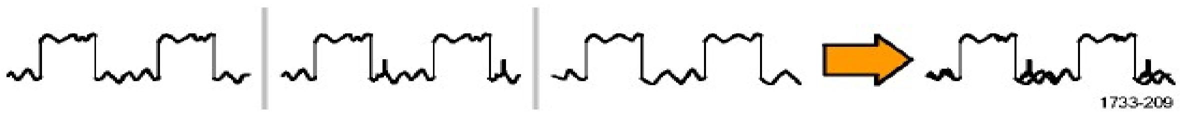
피크 검출 모드는 두 개의 연속적인 획득 간격에 포함된 모든 샘플 중에서 최대값과 최소값을 사용합니다. 이 모드는 보간되지 않는 실시간 샘플링에서만 작동하며 높은 주파수 글리치를 찾는 데 유용합니다.



Hi-Res 모드는 각 획득 간격에서 모든 샘플의 평균을 계산합니다. Hi-Res는 고해상도, 저대역폭 파형을 제공합니다.

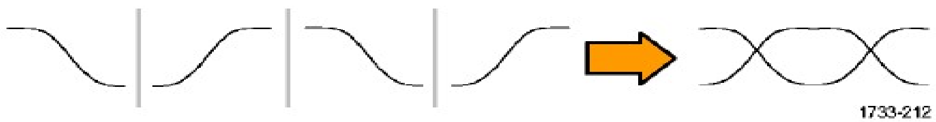


엔벨로프 모드는 많은 획득 중에서 최고 및 최저 레코드 포인트를 찾습니다. 엔벨로프는 각 개별 획득을 위해 피크 검출을 사용합니다.

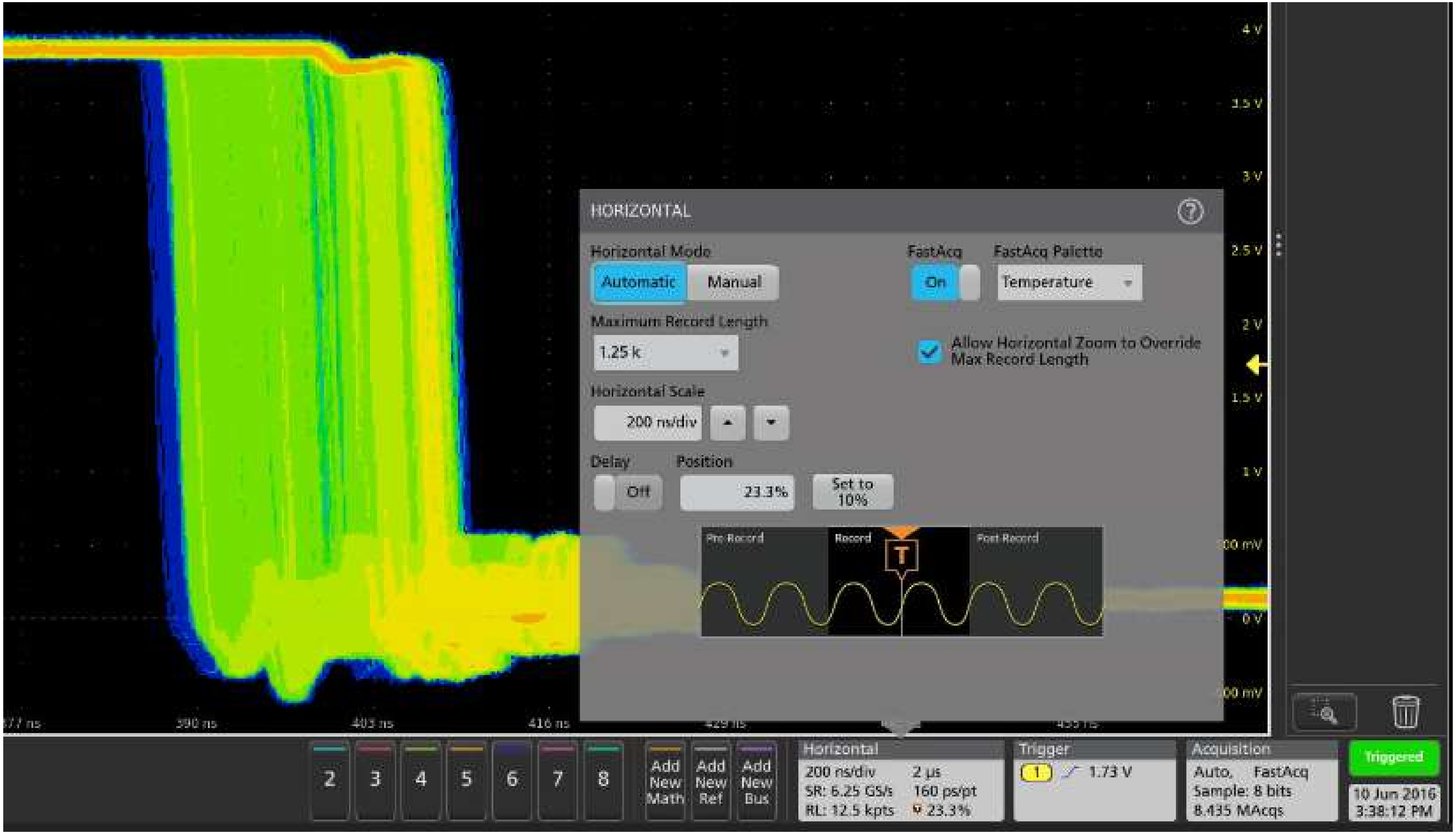


평균 모드는 많은 획득 중에서 각 레코드 포인트에 대해 평균 값을 계산합니다. 평균은 각 개별 획득에 대해 샘플 모드를 사용합니다. 랜덤 노이즈를 줄이려면 평균 모드를 사용하십시오.

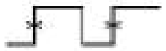
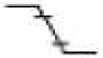
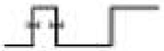
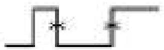
파형 데이터베이스 모드는 여러 획득에 대한 소스 파형 데이터의 3차원 누적입니다. 데이터베이스에는 진폭 및 타이밍 정보뿐 아니라 특정 파형 포인트(시간 및 진폭)를 획득한 횟수가 포함됩니다.



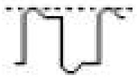
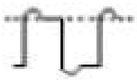
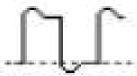
Hori/Acq - Horizontal Setup



Measurement – Time measurement

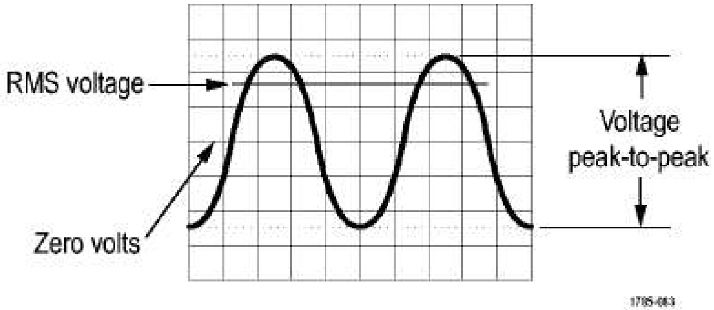
Frequency		The first cycle in a waveform or gated region. Frequency is the reciprocal of the period; it is measured in hertz (Hz) where one Hz is one cycle per second.
Period		The time required to complete the first cycle in a waveform or gated region. Period is the reciprocal of frequency and is measured in seconds.
Rise Time		The time required for the leading edge of the first pulse in the waveform or gated region to rise from the low reference value (default = 10%) to the high reference value (default = 90%) of the final value.
Fall Time		The time required for the falling edge of the first pulse in the waveform or gated region to fall from the high reference value (default = 90%) to the low reference value (default = 10%) of the final value.
Delay		The time between the mid reference (default 50%) amplitude point of two different waveforms. See also *Phase*.
Phase		The amount of time that one waveform leads or lags another waveform, expressed in degrees where 360° makes up one waveform cycle. See also *Delay*.
Positive Pulse Width		The distance (time) between the mid reference (default 50%) amplitude points of a positive pulse. The measurement is made on the first pulse in the waveform or gated region.
Negative Pulse Width		The distance (time) between the mid reference (default 50%) amplitude points of a negative pulse. The measurement is made on the first pulse in the waveform or gated region.
Positive Duty Cycle		The ratio of the positive pulse width to the signal period expressed as a percentage. The duty cycle is measured on the first cycle in the waveform or gated region.
Negative Duty Cycle		The ratio of the negative pulse width to the signal period expressed as a percentage. The duty cycle is measured on the first cycle in the waveform or gated region.

Measurement – Amplitude measurement

Peak-to-peak		The absolute difference between the maximum and minimum amplitude in the entire waveform or gated region.
Amplitude		The high value less the low value measured over the entire waveform or gated region.
Max		The most positive peak voltage. Max is measured over the entire waveform or gated region.
Min		The most negative peak voltage. Min is measured over the entire waveform or gated region.
High		This value is used as 100% whenever high reference, mid reference, or low reference values are needed, such as in fall time or rise time measurements. Calculate using either the min/max or histogram method. The min/max method uses the maximum value found. The histogram method uses the most common value found above the midpoint. This value is measured over the entire waveform or gated region.
Low		This value is used as 0% whenever high reference, mid reference, or low reference values are needed, such as in fall time or rise time measurements. Calculate using either the min/max or histogram method. The min/max method uses the minimum value found. The histogram method uses the most common value found below the midpoint. This value is measured over the entire waveform or gated region.
Positive Overshoot		This is measured over the entire waveform or gated region and is expressed as: Positive Overshoot = (Maximum – High) / Amplitude x 100%.
Negative Overshoot		This is measured over the entire waveform or gated region and is expressed as: Negative Overshoot = (Low – Minimum) / Amplitude x 100%.

Measurement – Amplitude measurement

Measurement	Description
Mean	The arithmetic mean over the entire waveform or gated region.
Cycle Mean	The arithmetic mean over the first cycle in the waveform or the first cycle in the gated region.
RMS	The true Root Mean Square voltage over the entire waveform or gated region.
Cycle RMS	The true Root Mean Square voltage over the first cycle in the waveform or the first cycle in the gated region.

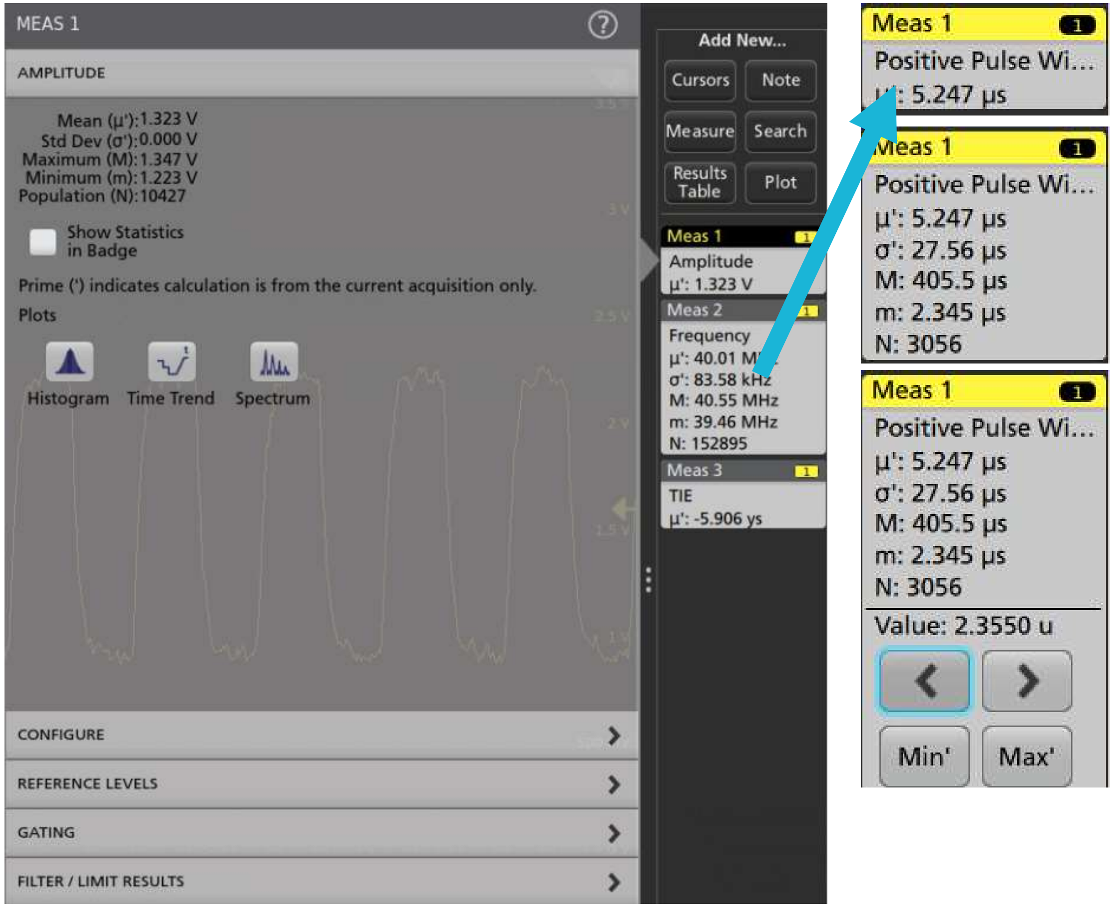


Measurement

MEASUREMENT AND RESULTS BAR

- **Single tap** to Add New..
  - Plots
  - Search
  - Measurements
  - Notes
  - Cursors
  - Results Table

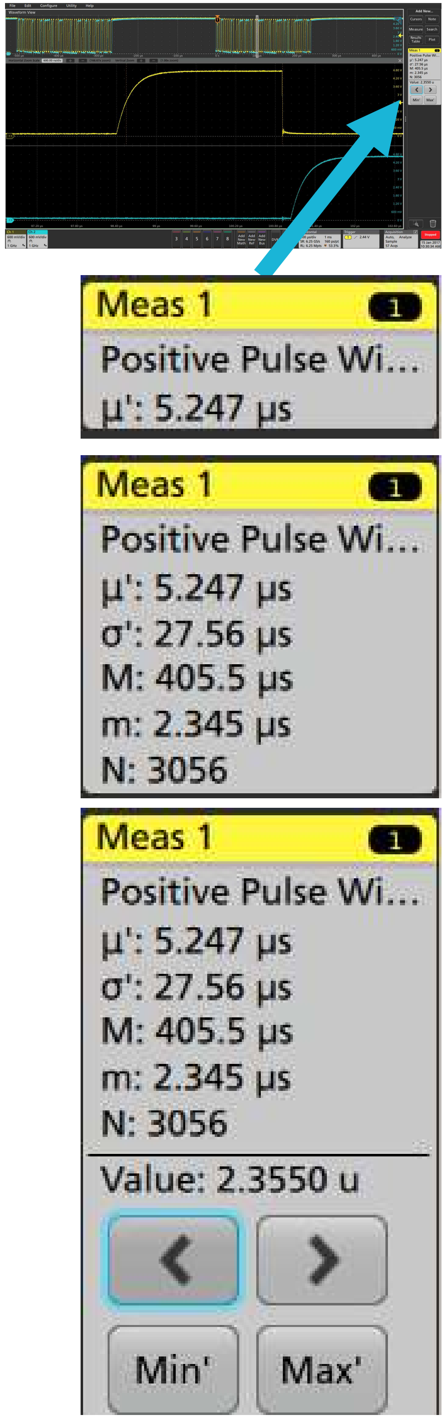
- **Double tap** badges to access measurement configure
  - Easily add measurement plots
  - Turn on statistics
  - Local or Global reference levels
  - Local or Global gating parameters



Other Features

MEASUREMENT BADGES, STATS AND NAVIGATION

- ***New*** way of displaying measurements has been implemented for better visibility
  - An apostrophe symbol → ‘ ← means the value is calculated over the current acquisition
  - No apostrophe symbol means calculated over all acquisitions until a stop or clear occurs
  - All current, and total measurements can be seen in a Results table
- User can choose to display statistics in the badge
- When stopped, single tap the badge to expand and reveal navigation controls
  - Just like front panel ← and → buttons
  - Min’ and Max’ buttons go to Min and Max values in the current record



Thank you