Tektronix

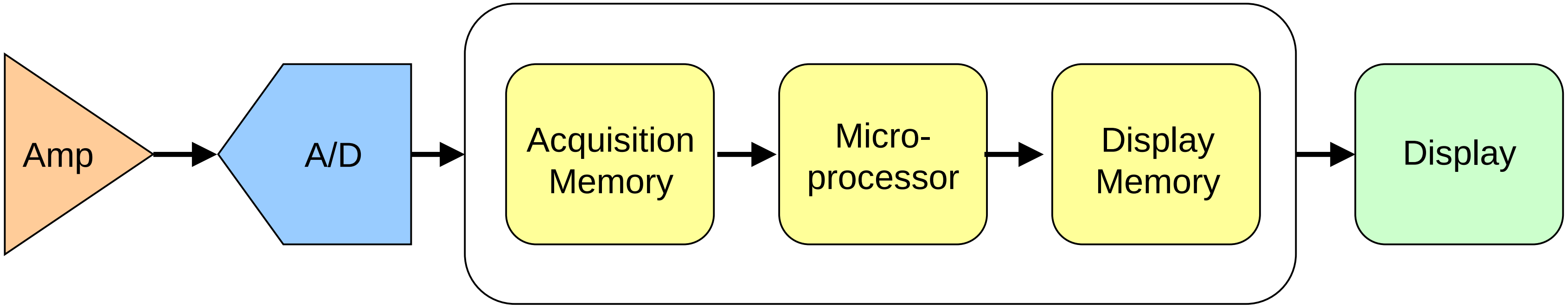
Oscilloscope Basic Training

Contents

Introduction

How Does an Oscilloscope Work?

- Signal Processing on the oscilloscope

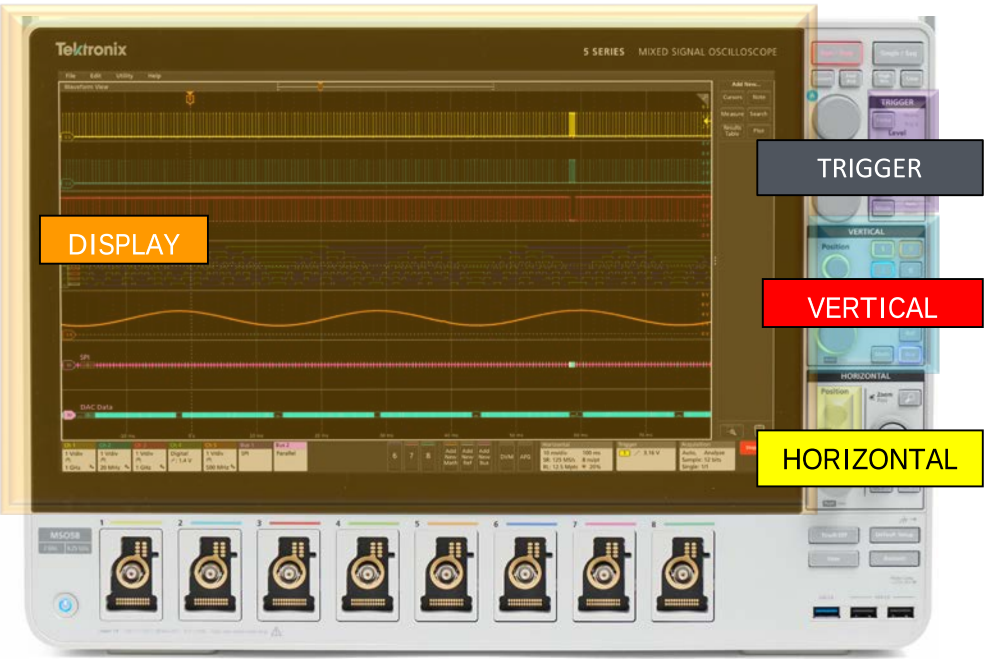


- **Scope bandwidth and Probe bandwidth**
- **Sample rate**
- **Record length**
- **Trigger and Signal processing**

MSO58 MSO54 MSO56

Oscilloscope structure

MDO3000, MDO4000C 시리즈



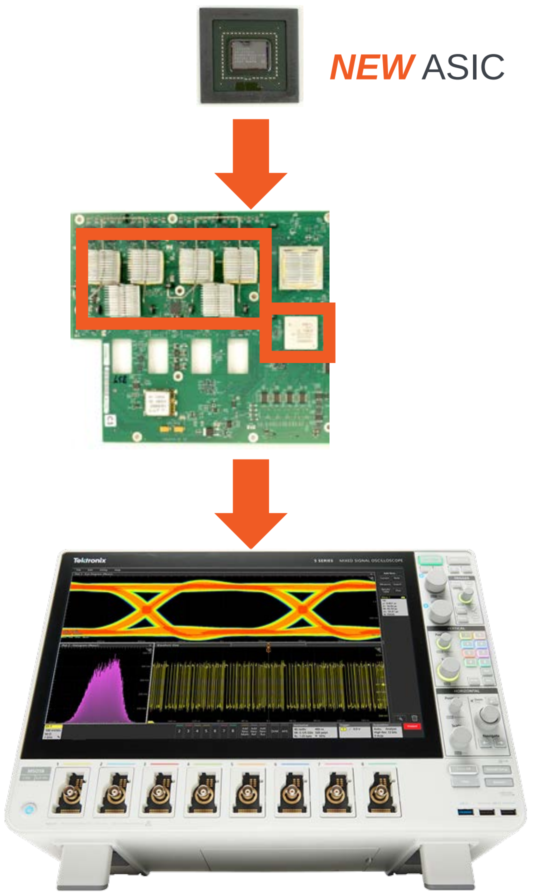
신규 오실로스코프
MSO 5 시리즈

http://news.tektronix.com/2018-01-04-Tektronix-5-Series-MSO-Named-Product-of-the-Year-by-Electronic-Products-Magazine

Brand New Scope Platform

KEY ADVANTAGES OF 5 SERIES MSO

- ***NEW*** **ASIC** combines traditional ADC, Demux, Trigger, and logic analysis:
  - More channels per instrument
  - Tighter integration between analog and digital channels
  - Flexible configurations to meet any debug challenge



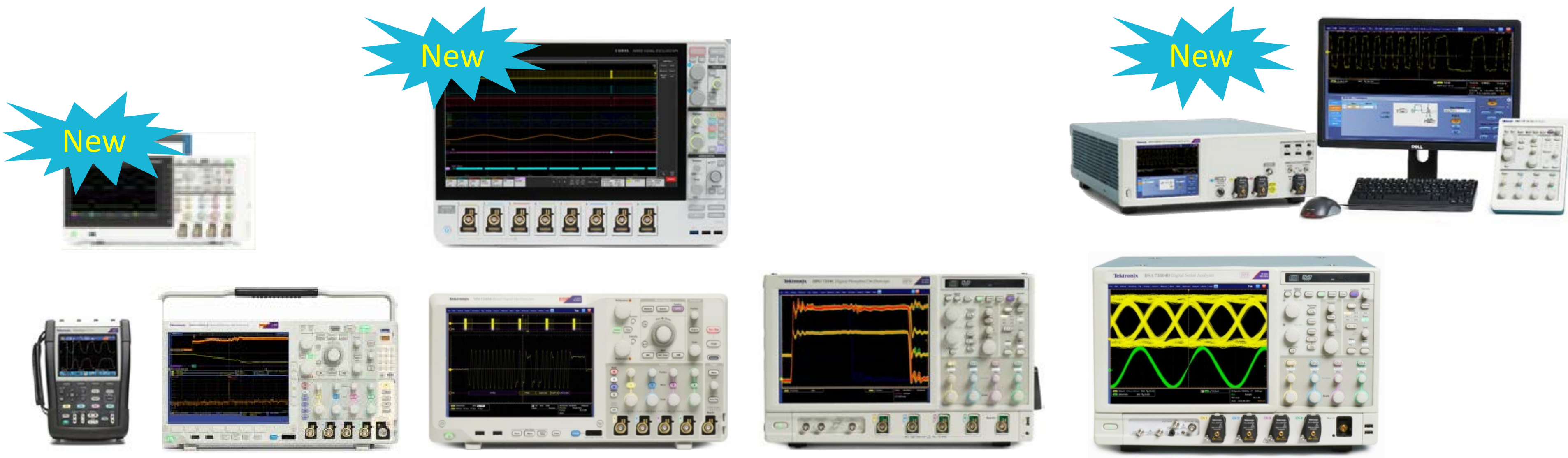
- ***NEW*** **12-bit** technology (16-bit with High-Res)
- ***NEW*** **Lower-noise** front-end amplifier
- ***NEW*** **FlexChannel™** input
- ***NEW*** software architecture
- ***NEW*** industrial design
- ***NEW*** user interface

The 5 Series MSO offers **FastAcq**, with over 500,000 wfms/sec

Real Time Oscilloscope Products

- **Basic Scopes**
  - THS, TPS, TBS, TDS Series
- **Mixed Signal Scopes(MSO Series)**
  - New MSO5 Series
- **Mixed Domain Scopes(MDO Series)**
- **High Performance Scopes (DPO70KC/DX/SX series High Performance Scope)**

~ 2GHz | ~ 3.5GHz | 4GHz ~ 70GHz

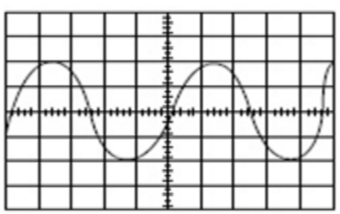


Oscilloscope

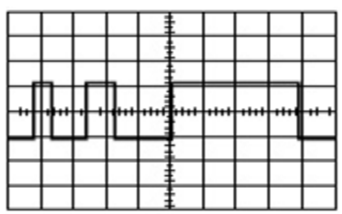
1. Observe.
   O.S.C observe the change of an electrical signal over time.



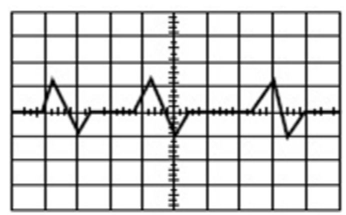

2. Display.
   O.S.C can display the observed waveform.



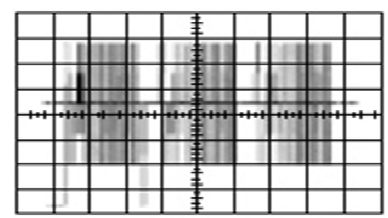
Sine Waves



Square & Rectangular Waves



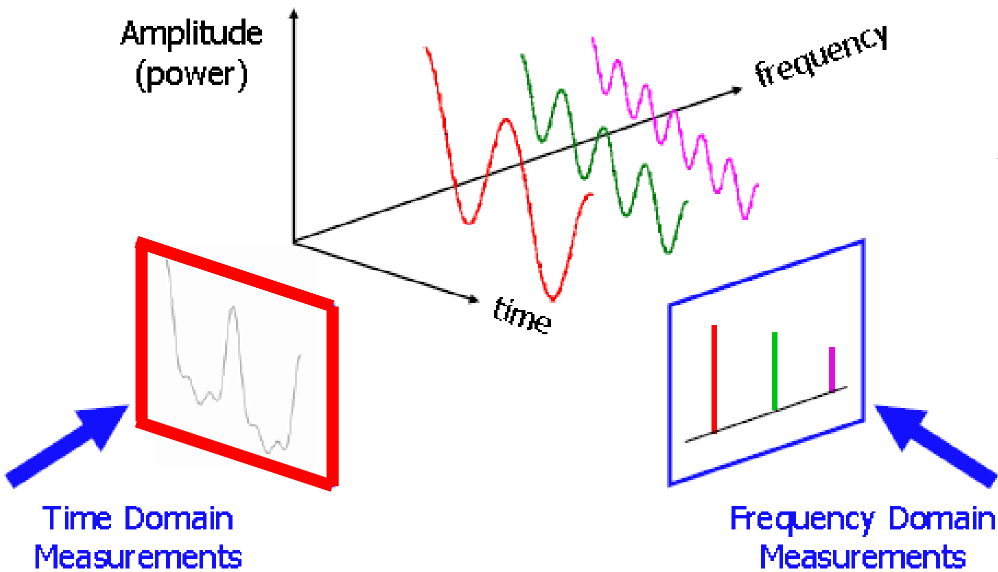
Sawtooth & Triangle Waves

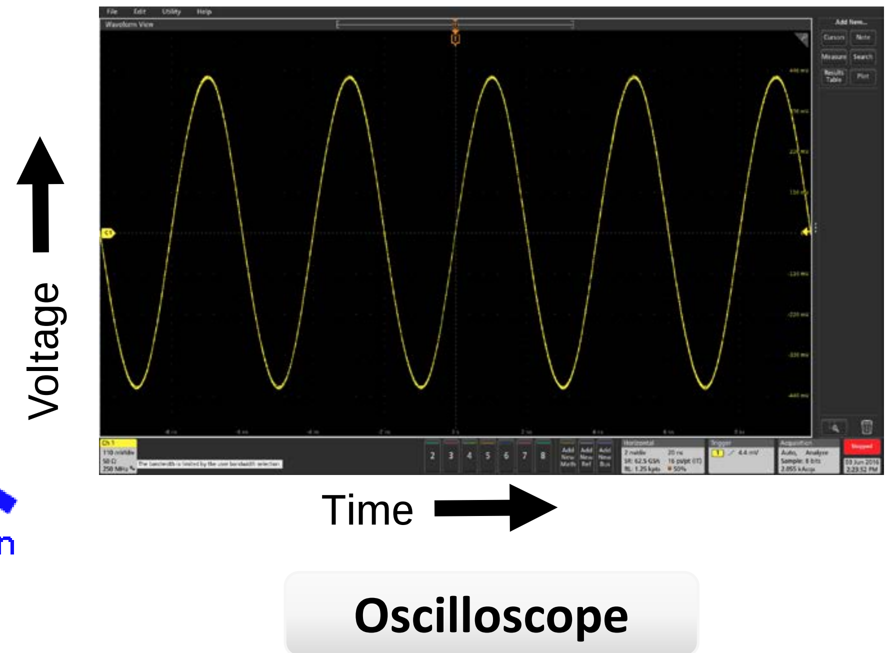


Complex Waves

What is the Oscilloscope?

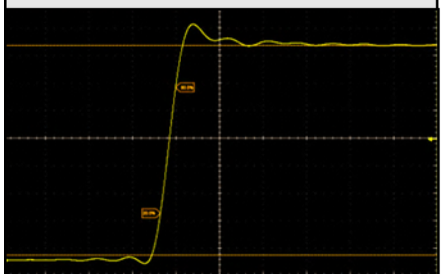
- Draws a graph of an electrical signal over time
  - Vertical (Y) axis is voltage or Current
  - Horizontal (X) axis is time





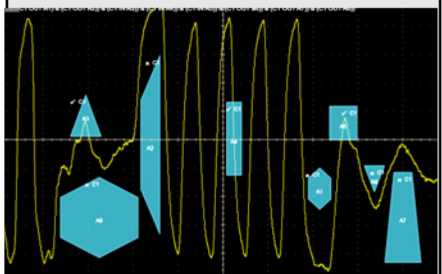
Oscilloscope Capabilities

Discover



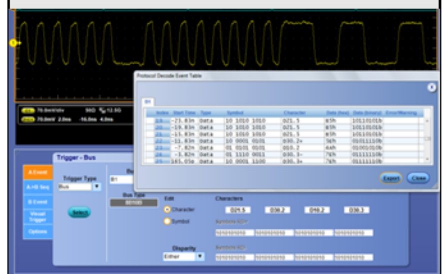
- Accurate signal representation
- Multi-channel acquisition without compromises
- Highly visible waveform content

Capture



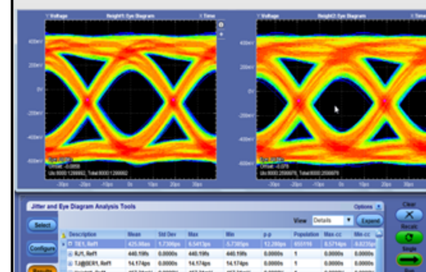
- Complex signal event capture
- Connectivity to DUT with high signal fidelity
- Access to decoded serial bus traffic

Search



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

Analyze



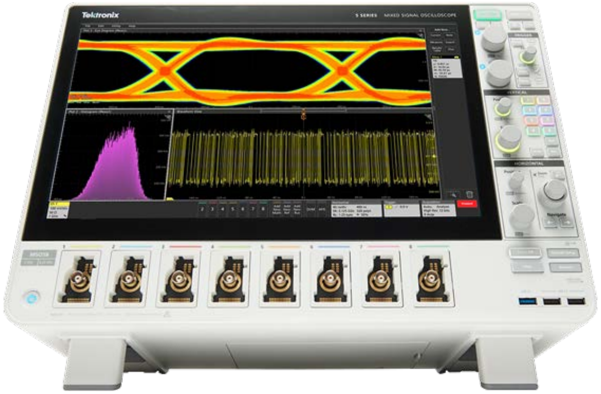
- Advanced jitter separation methods
- Accurate Serial Data compliance tests
- Fast data access for deeper analysis

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**

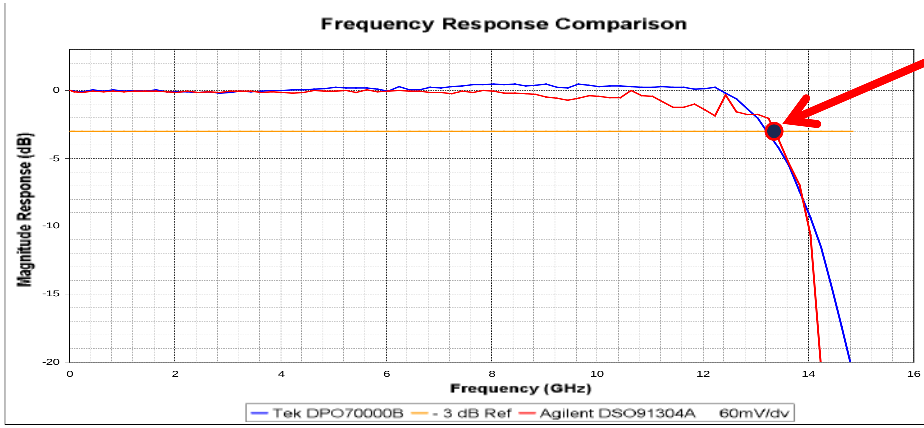


Bandwidth

Bandwidth

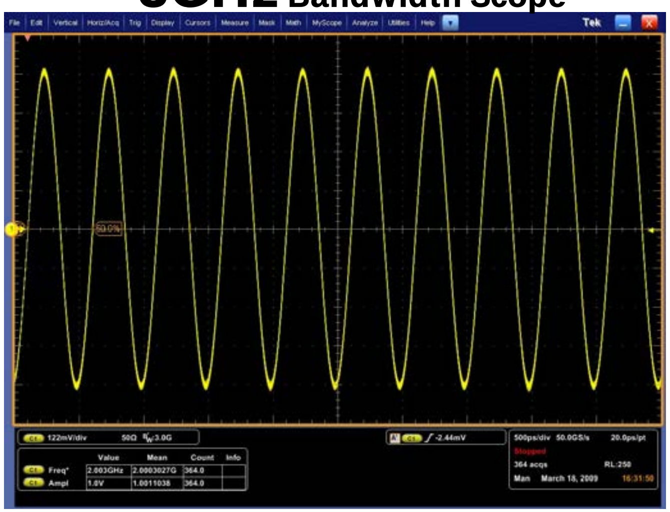
– Defined with Sine wave

70.7

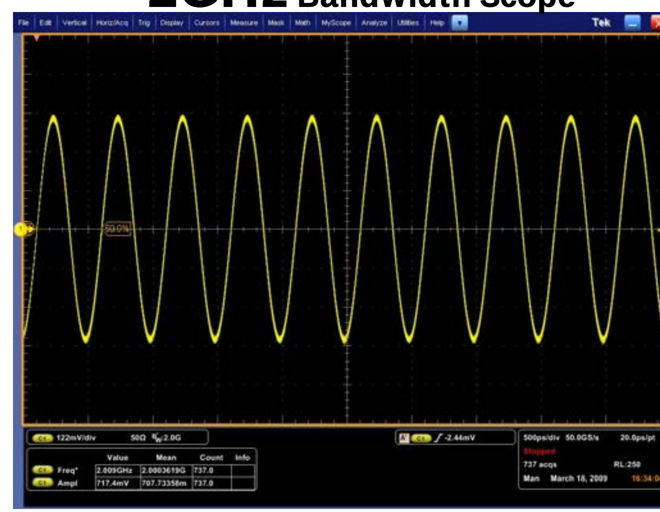


-3dB (Oscilloscope BW)

3GHz Bandwidth Scope



2GHz Bandwidth Scope



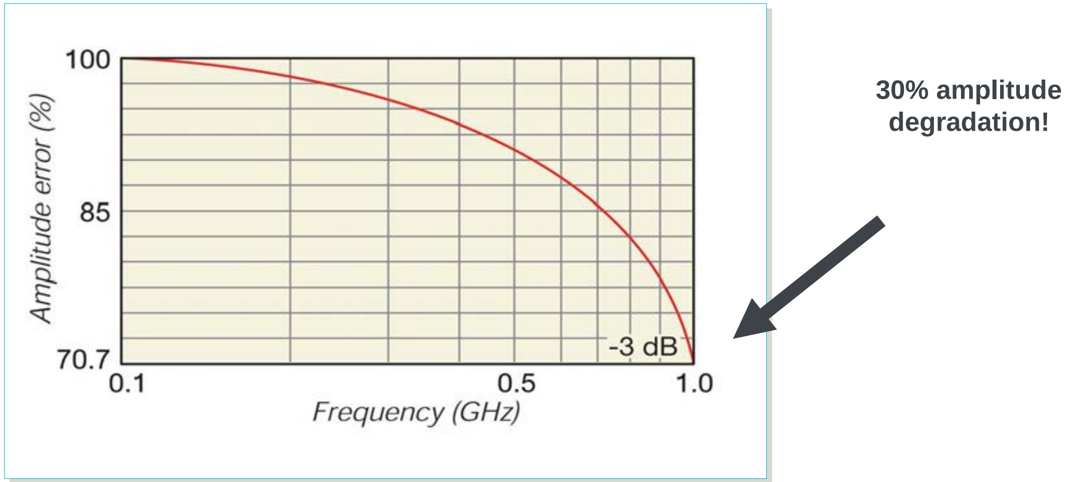
- Input Signal
  - Freq. : 2GHz
  - Amp. : 1Vpk-pk

Bandwidth

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

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

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



- 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.

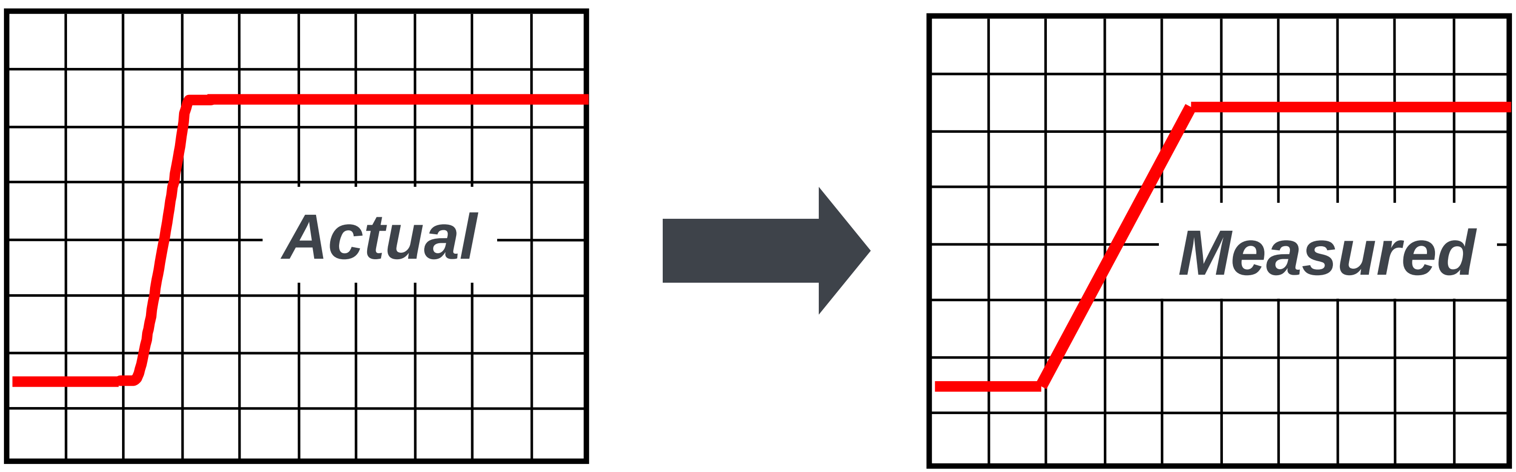
Signal Fidelity – Rise Time

- 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 $tr = \frac{0.35}{BW} = \frac{0.35}{3 \times 10^{6}} = 111ps$

and

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

Rise Time Concern

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

3GHz (111ps)
Scope Measurement

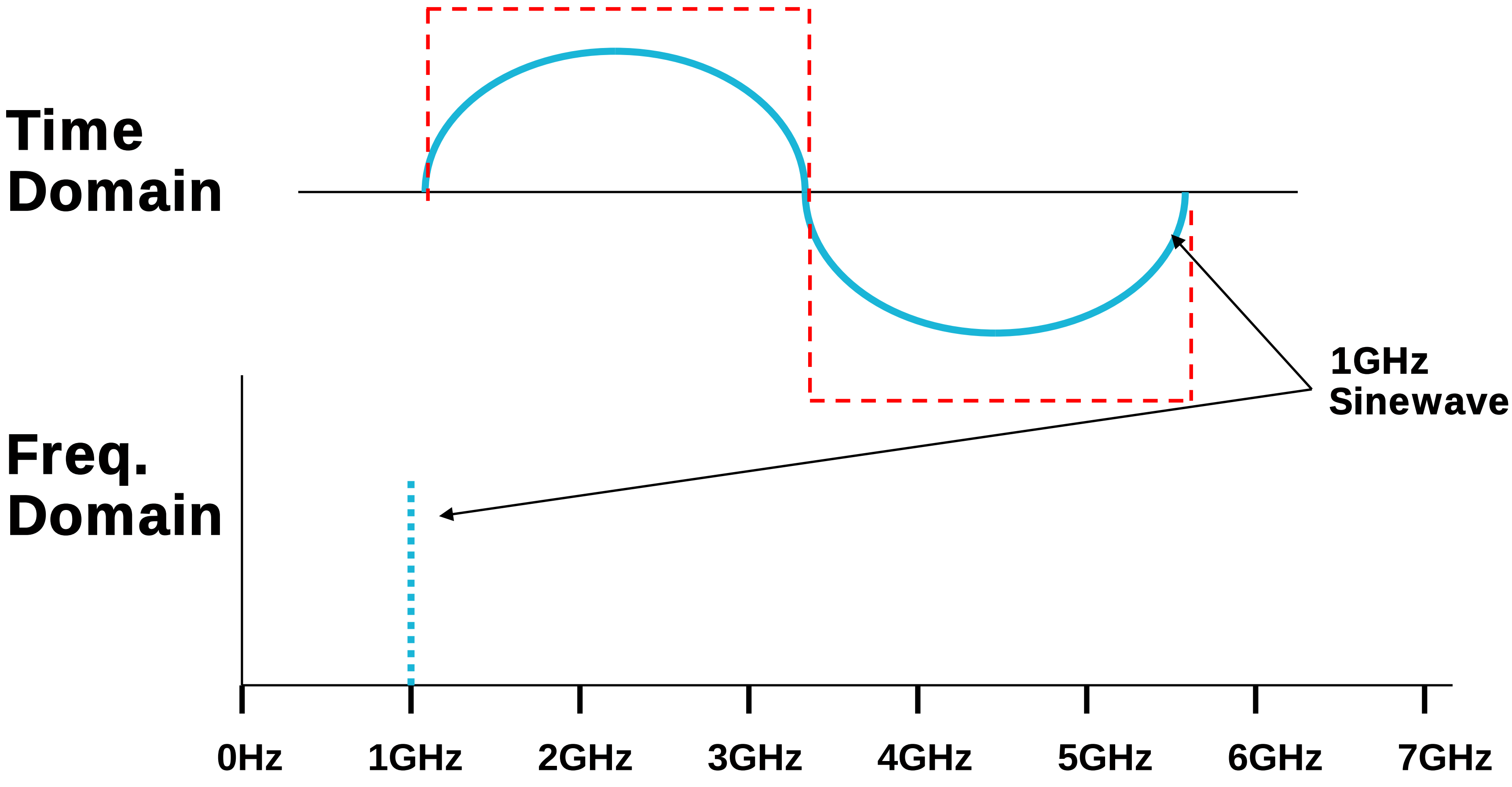
Scope Displayed tr = 512ps
Resulting in a <u>2.4%</u> error

1GHz (350ps)
Scope Measurement

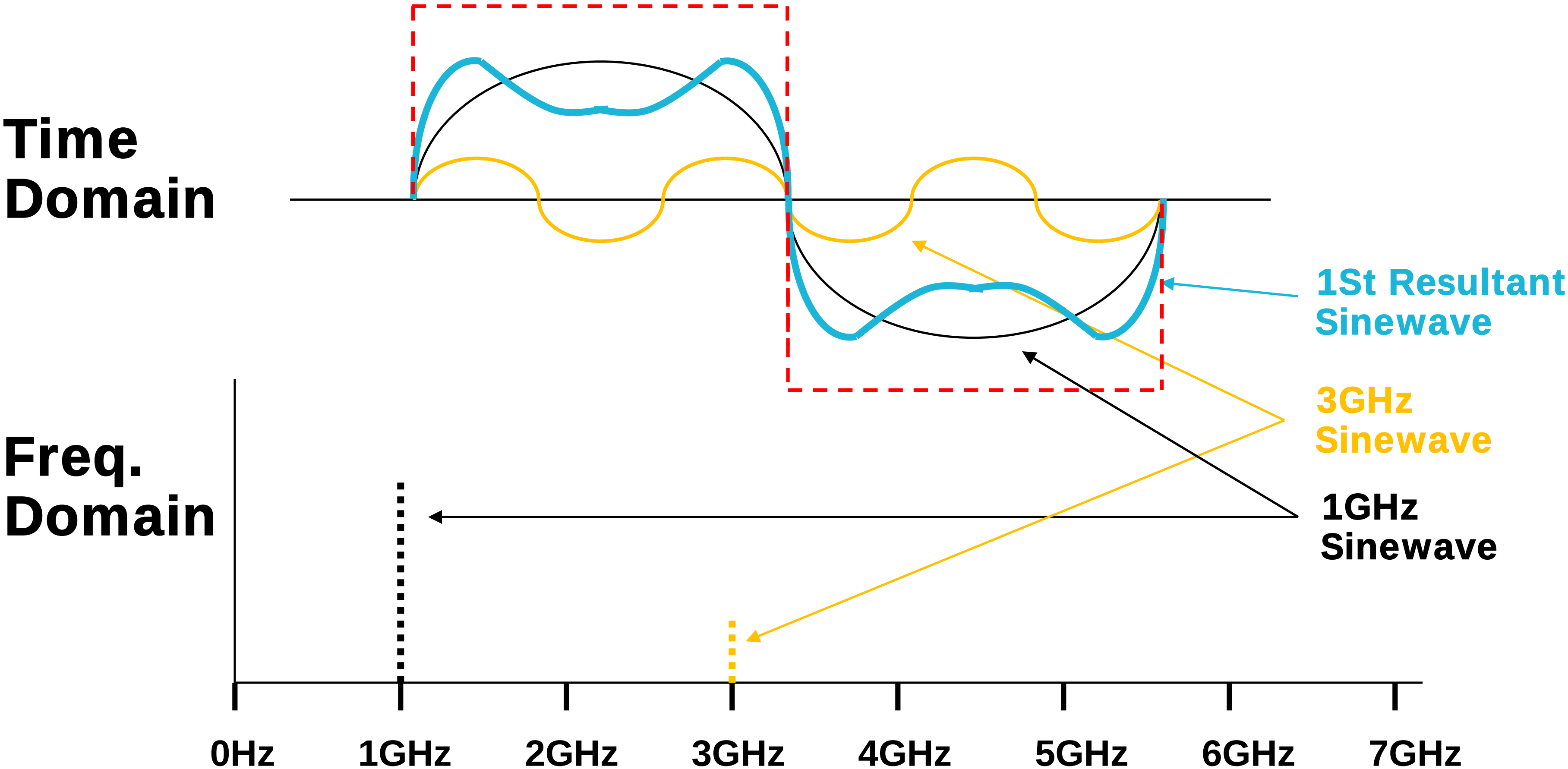
Scope Displayed tr = 610ps
Resulting in a <u>22%</u> error

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

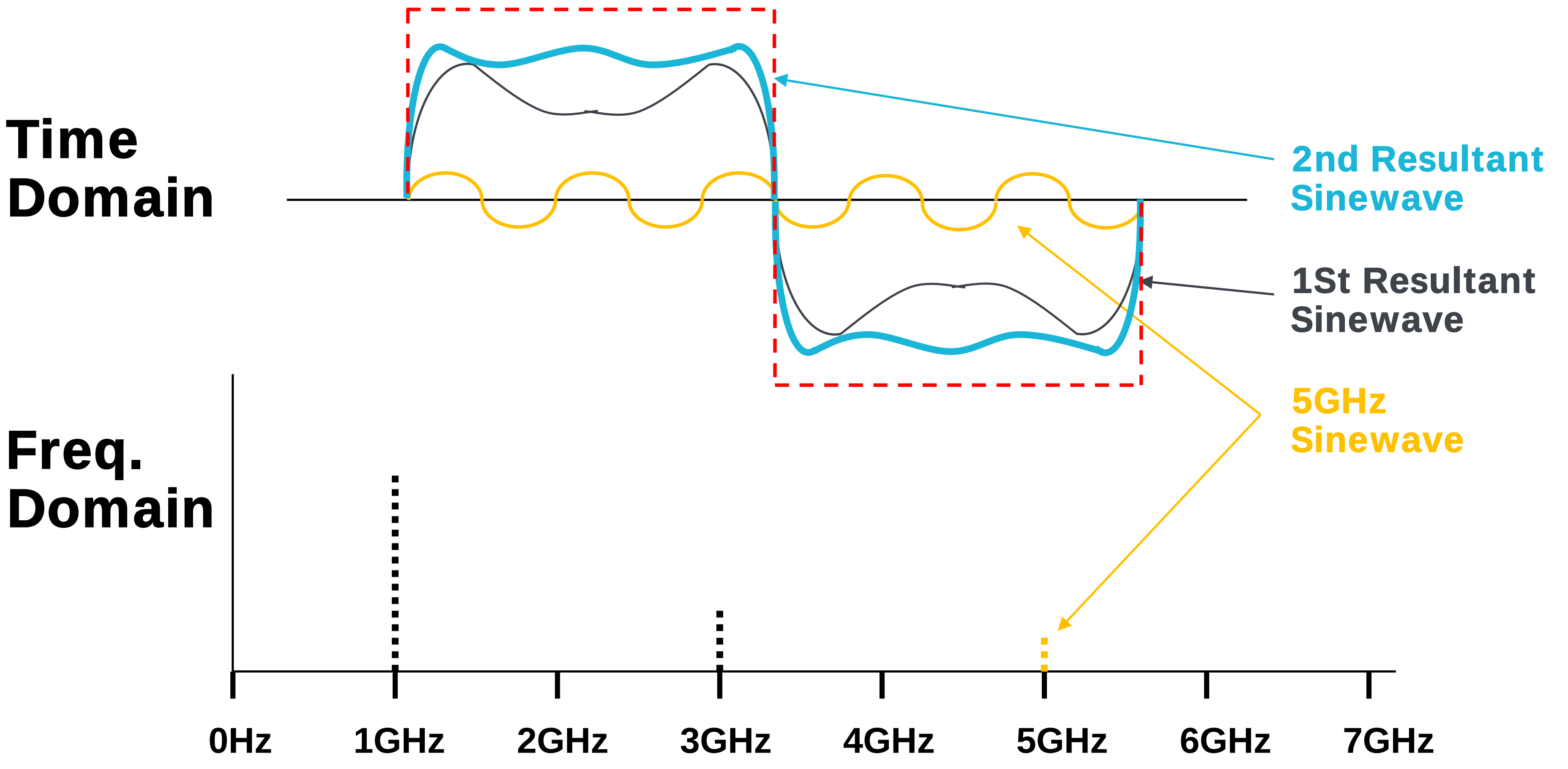
Rise Time vs. Signal Frequency



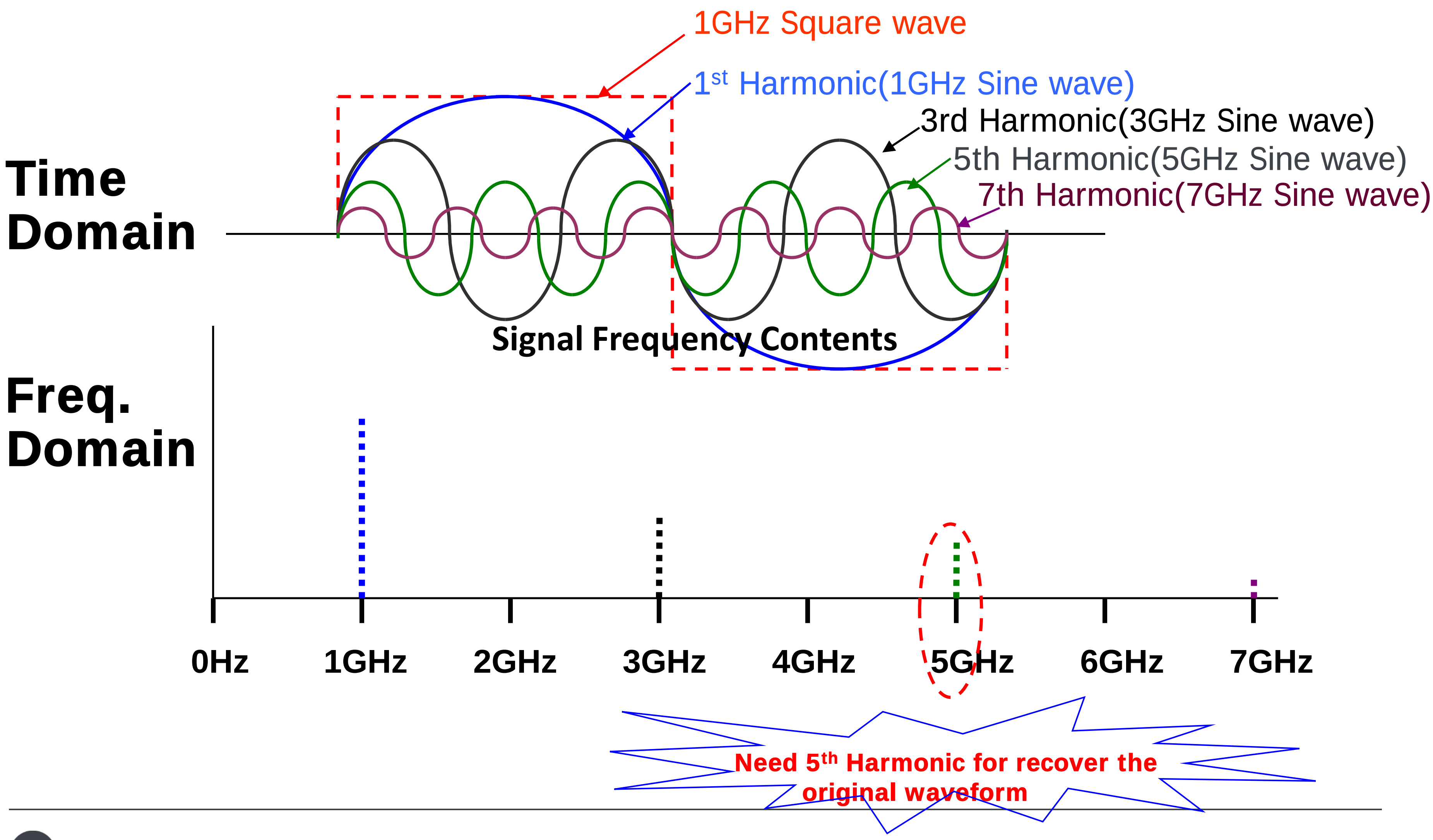
Rise Time vs. Signal Frequency



Rise Time vs. Signal Frequency

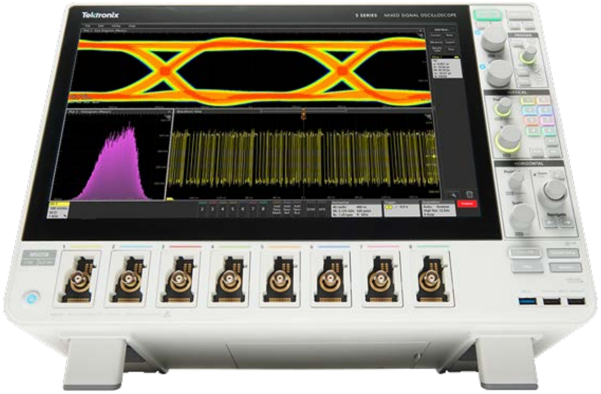


Rise Time vs. Signal Frequency



Hands-on Lab:#2

Understanding Bandwidth

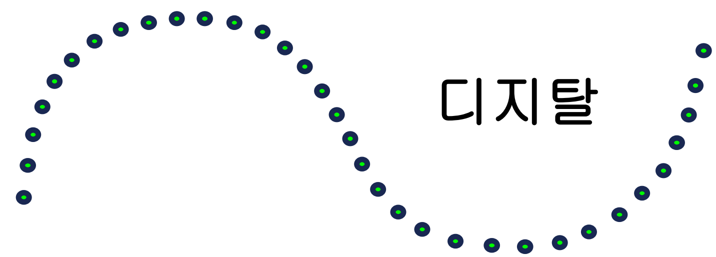


Sample Rate

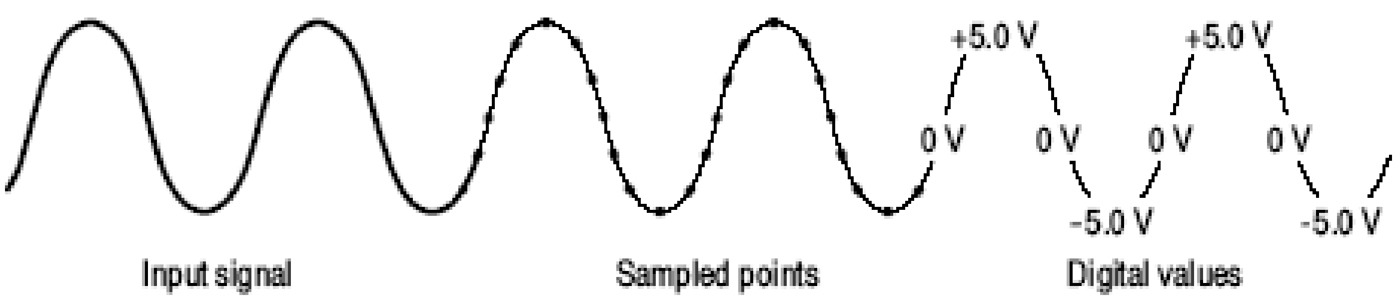
Record Length

A-D-C


아날로그

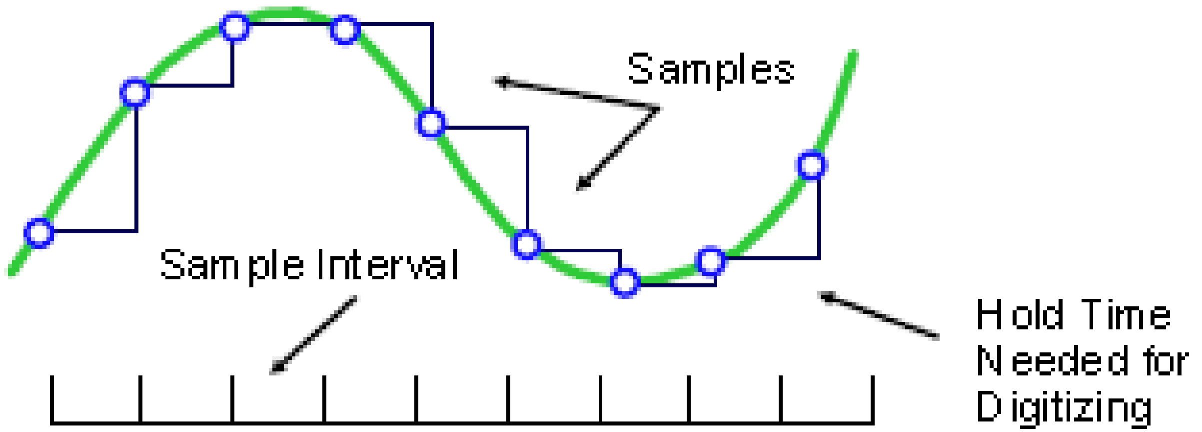

디지탈

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

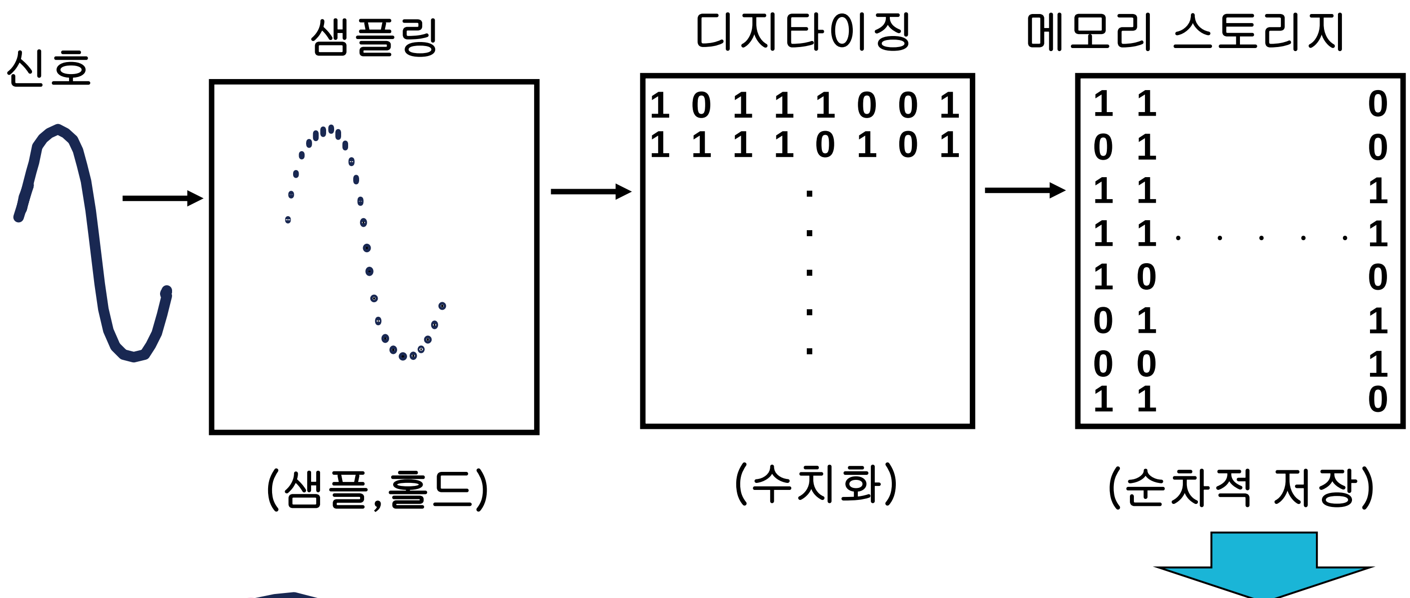
Sampling

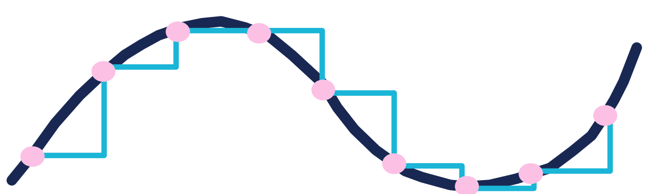
Taking Samples of an input signal at specific points in time

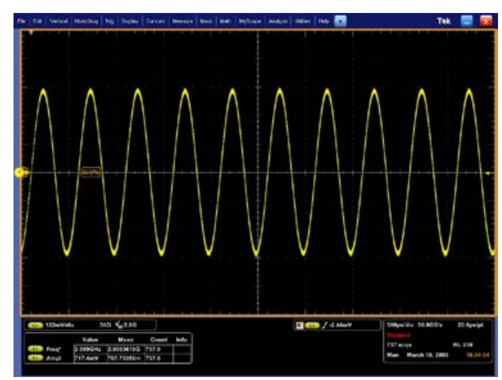


- Samples Equally Spaced in Time
- Sample Rate Measured in Sample/Second (S/s, kS/s, MS/s, GS/s)

Sampling process







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

Sampling Technology

- 실시간 샘플링**(RTS)**

  - Single Shot Event에 대한 실시간 **sampling**

  - 파형의 **update**가 빠르다

  - ADC의 **Sampling Rate**와 동일

  - 장비 가격이 비싸다

- 등가시간 샘플링**(ETS) : Random, Sequential**

  - 신호의 반복성을 이용한 반복적 샘플링

  - Sampling Rate는 상당히 높다

  - update 속도가 느리다

  - 낮은 **ADC** 의 **SR**로도 높은 **SR**가능

Real Time Sampling

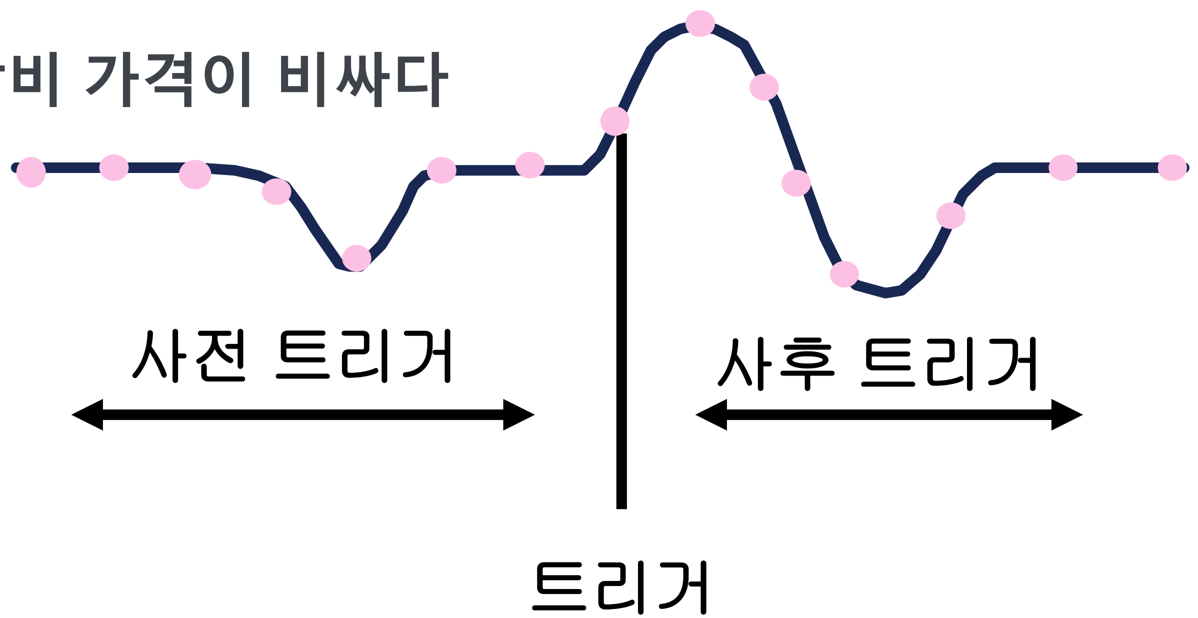
- 실시간 샘플링(RTS)

  - Single Shot Event에 대한 실시간 sampling

  - 파형의 update가 빠르다

  - ADC의 Sampling Rate와 동일

  - 장비 가격이 비싸다



Equivalent Time Sampling

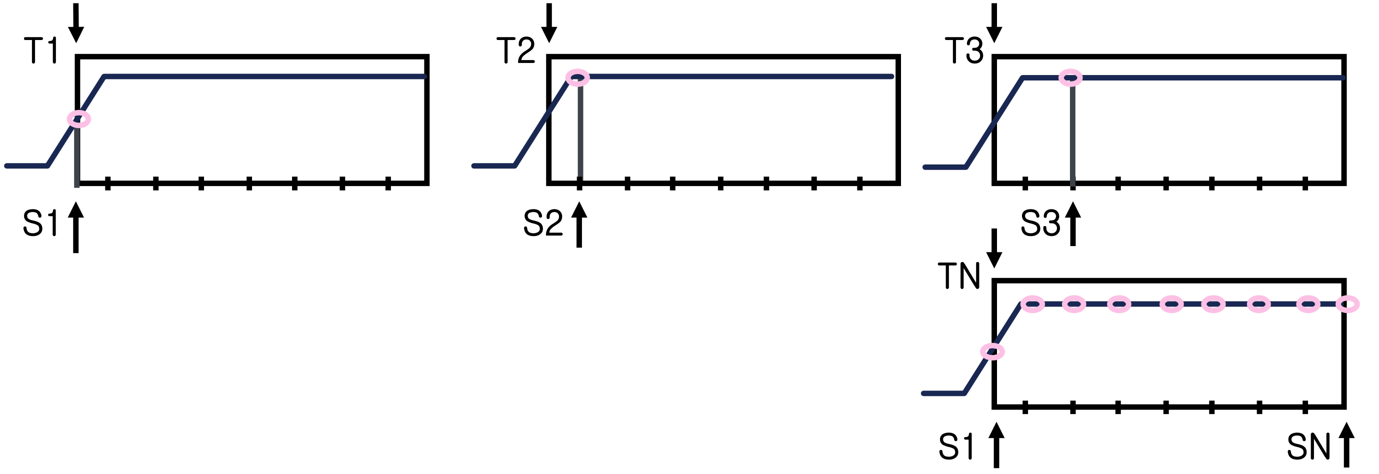
- 등가시간 샘플링**(ETS) : Random, Sequential**

  - 신호의 반복성을 이용한 반복적 샘플링

  - Sampling Rate는 상당히 높다

  - update 속도가 느리다

  - 낮은 ADC 의 SR로도 높은 SR가능



Interpolation

- Linear Interpolation

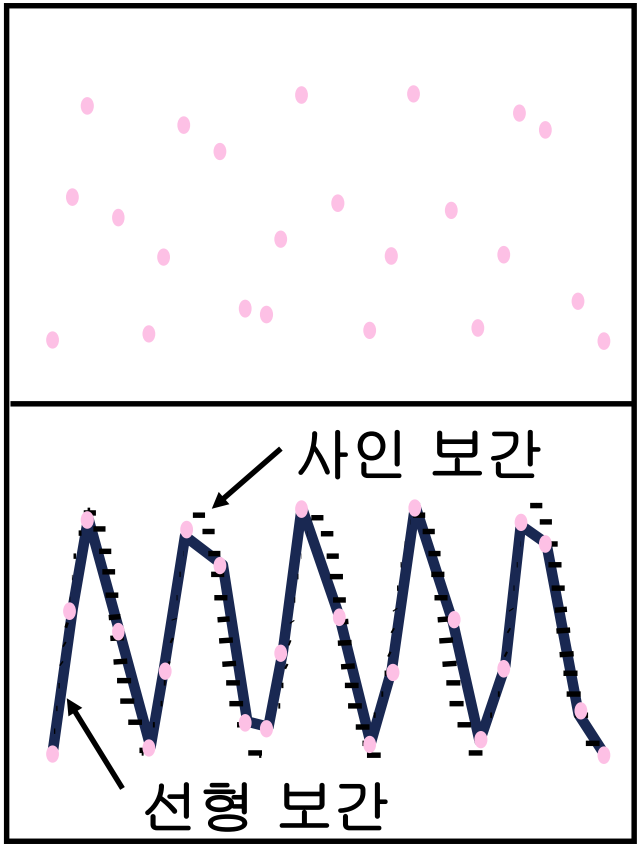
  – 포착된 샘플들을 직선으로 연결.

  – 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

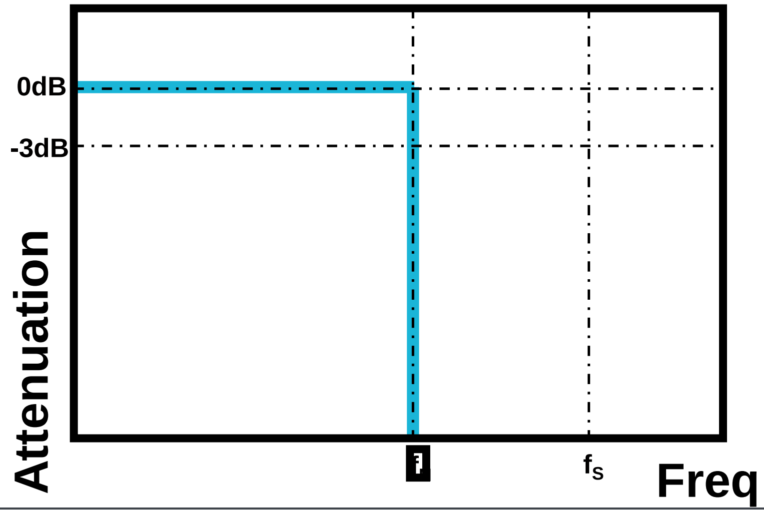
Nyquist's sampling theorem

- **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, f_{max}, is sometimes called the Nyquist frequency (f_N).

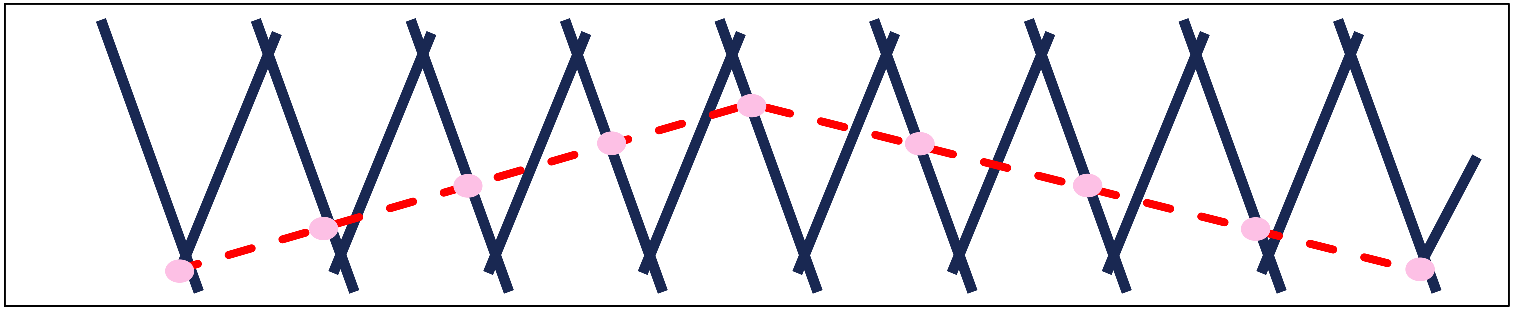


Aliasing

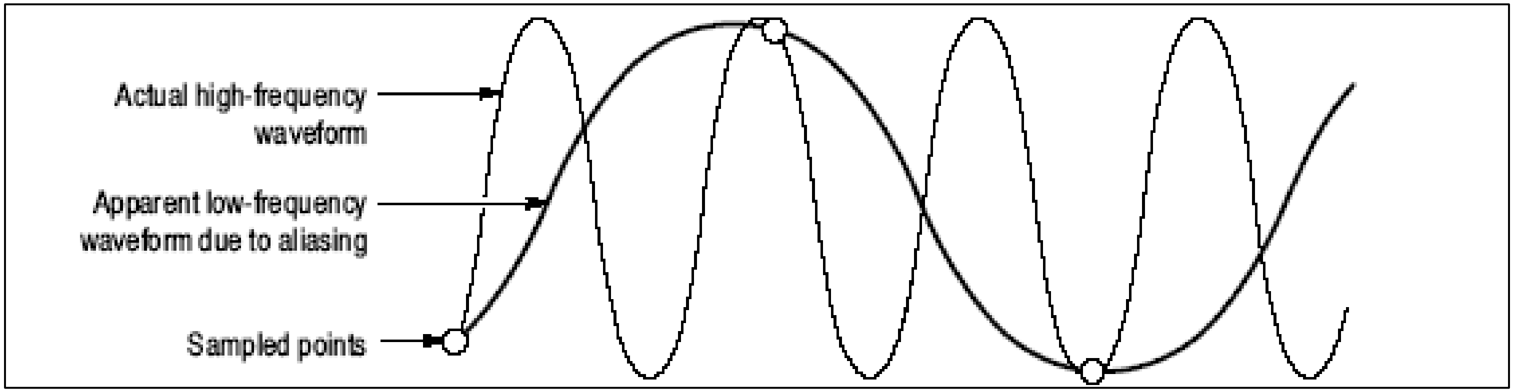
- ☐ Nyquist's Sampling Theory
  - Late 1920s Harry Nyquist, an AT&T scientist
  - "For periodic functions, if you sampled at a rate that was at least twice as fast as the signal of interest, then no information (data) would be lost upon reconstruction."
  - Nyquist, Harry, "Certain topics in Telegraph Transmission Theory," published in 1928

Aliasing

- 신호에 대한 언더 샘플링에 의해 발생

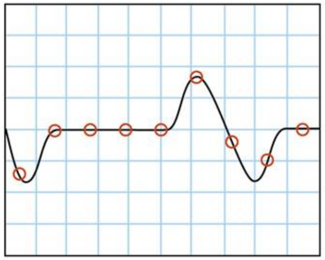


- 파형을 낮은 주파수로 재현시킨다.



Sample Rate

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



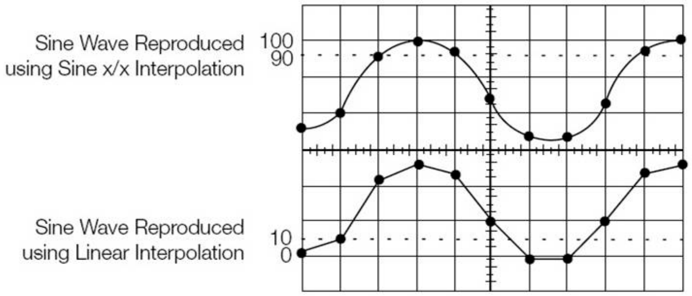
- Required Sample Rate

Sample Rate > 2.5 X $f_{Highest}$

For sin(x)/x interpolation

Sample Rate > 10 X $f_{Highest}$

For linear interpolation



5X oversampling is recommended to avoid aliasing and to capture signal details.

Memory - Record Length

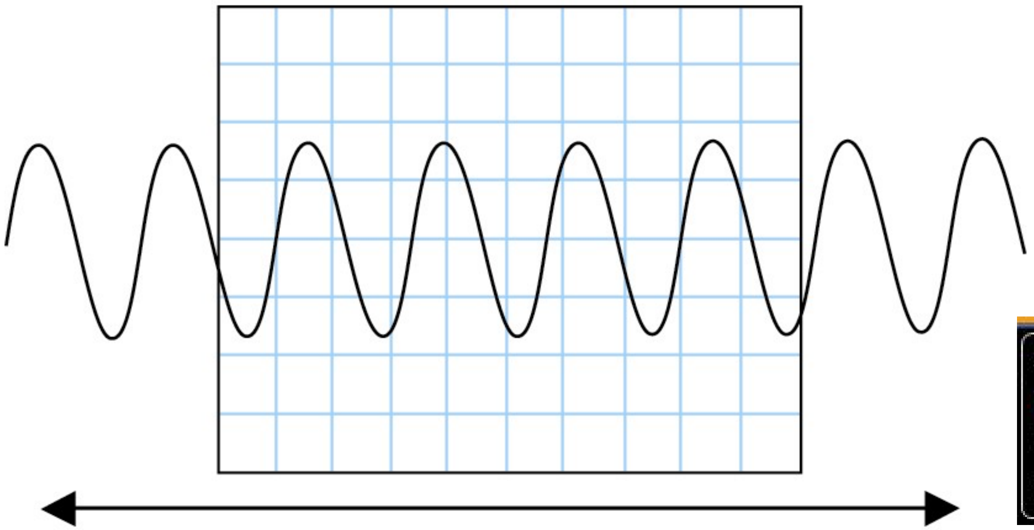
- Step

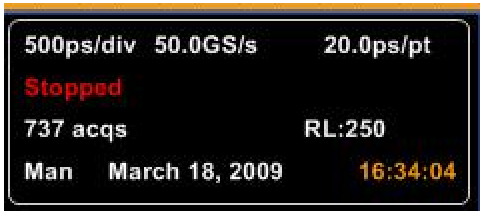
1. **Determine Required Resolution Between Samples = T_r**
   - **$1 / T_r \leq$ Scope Sample Rate (Real Time Sampling Mode)**

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

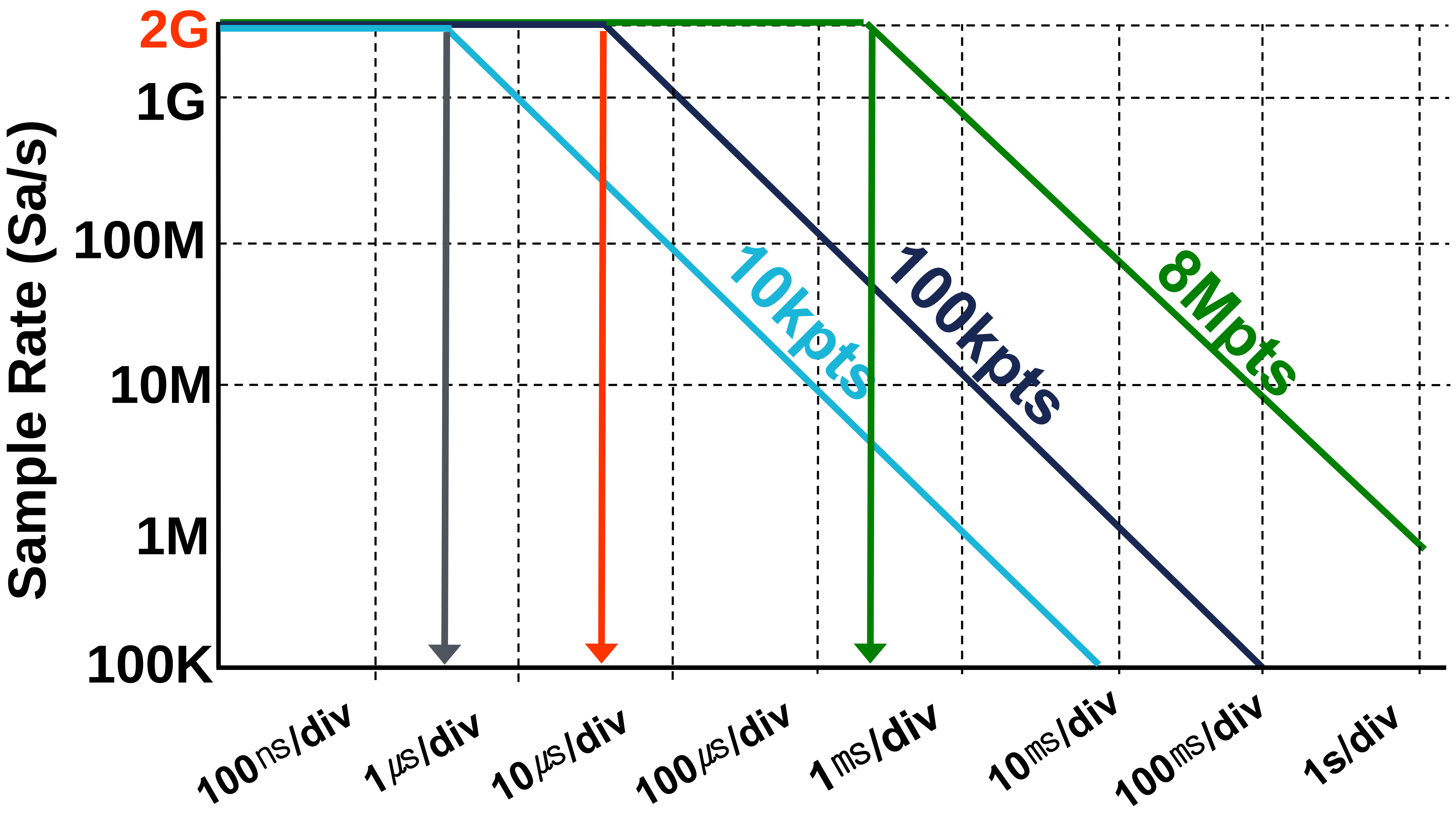




$$\text{Time} = \frac{\text{Record Length}}{\text{Sample Rate}}$$

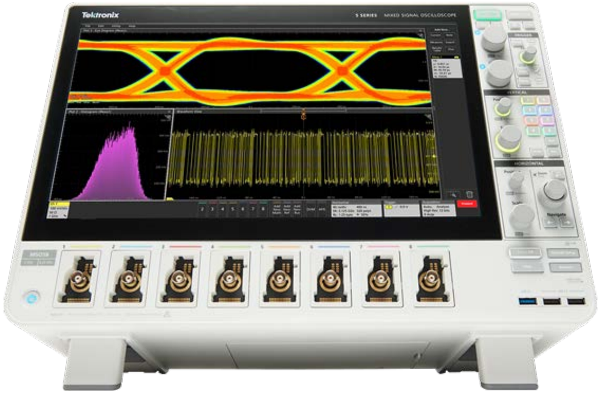
Memory - Record Length

Trade off between Sample rate and Record Length



Hands-on Lab:#3

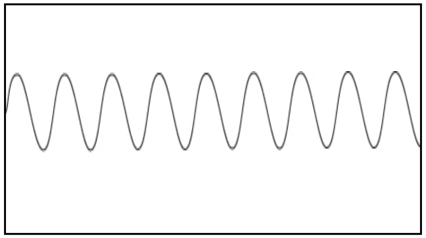
Sample rate vs. Record length
Aliasing



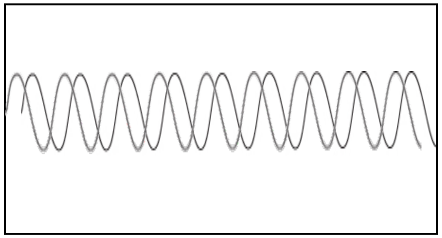
Trigger System

Trigger System and Controls

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

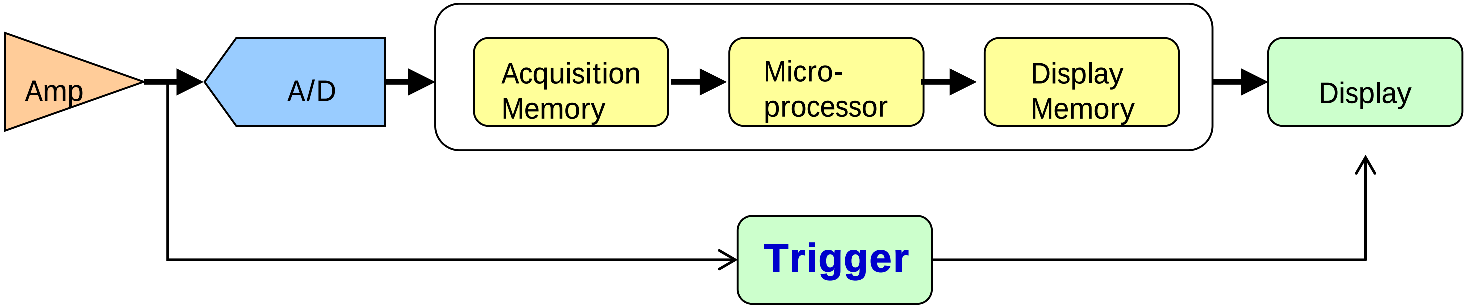


Triggered Display
(Normal Mode)



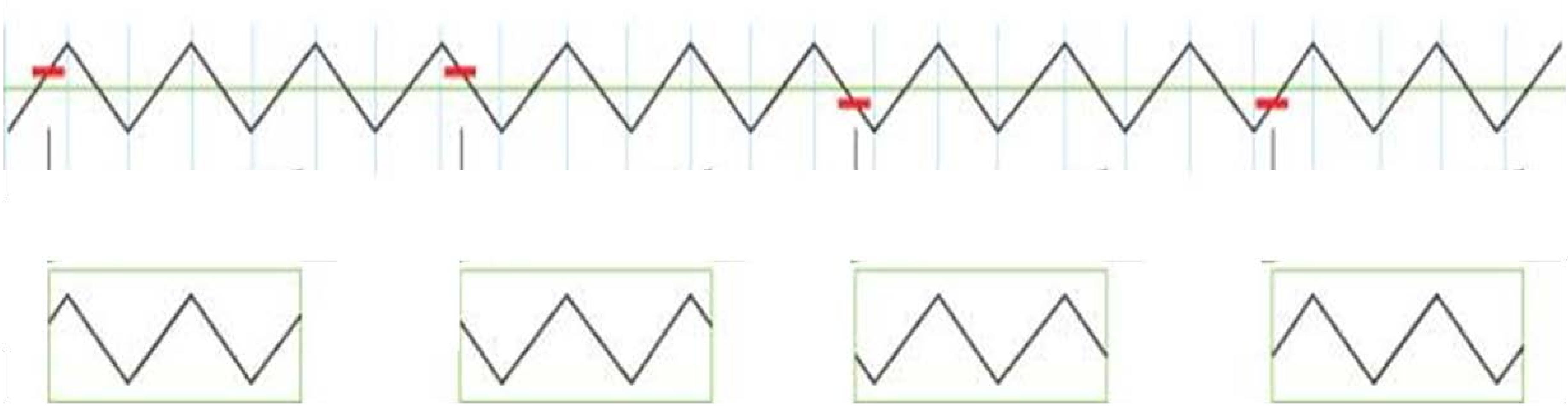
Untriggered Display
(Auto Mode)

- **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.



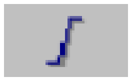
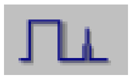
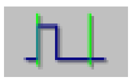
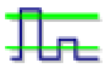
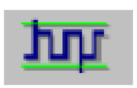
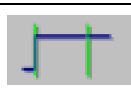
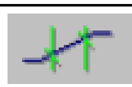
Trigger Level and Slope

- 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

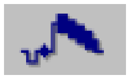
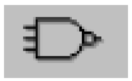
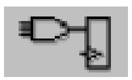
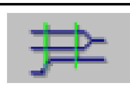
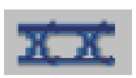


Threshold: +	Threshold: +	Threshold: -	Threshold: -
Slope: +	Slope: -	Slope: -	Slope: +

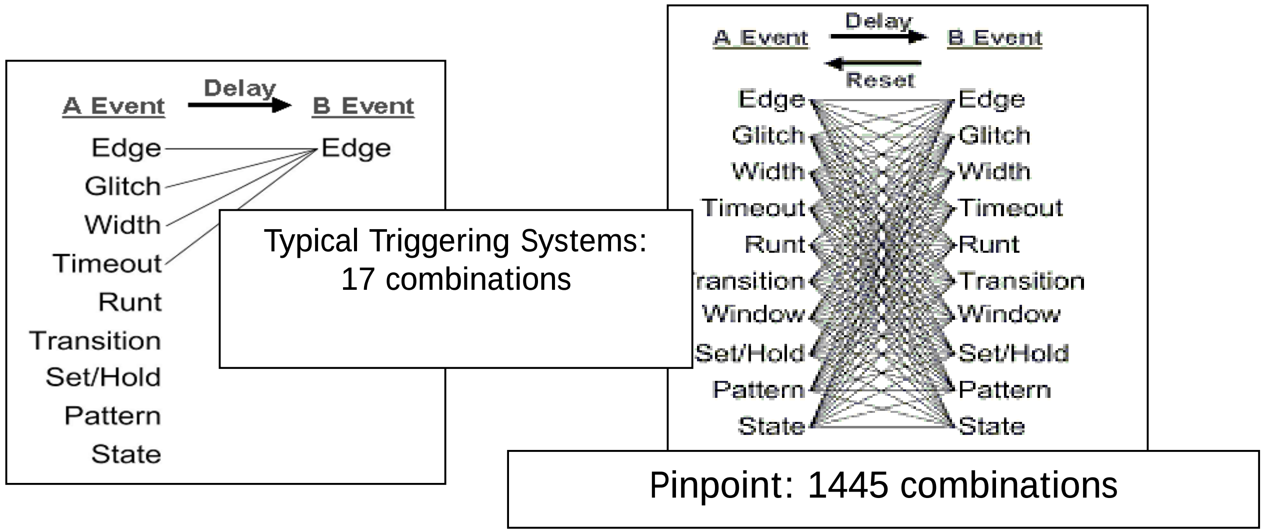
오실로스코프 트리거 종류 및 기능

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.

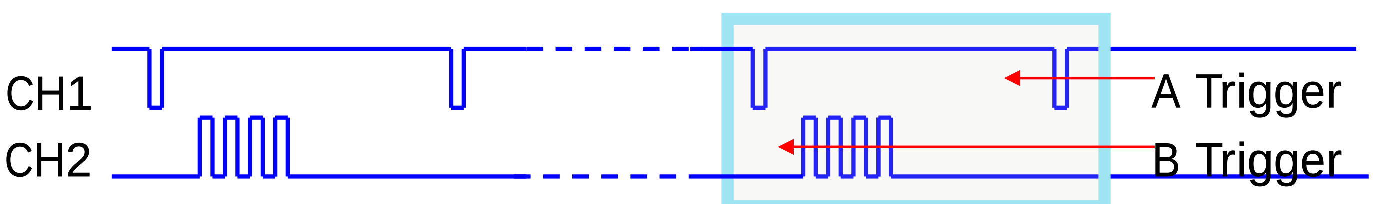
오실로스코프 트리거 종류 및 기능

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

1. Trigger Type : etc

Hands-on Lab:#5

I2C validation

1. I2C probing

2. I2C Bus decoding

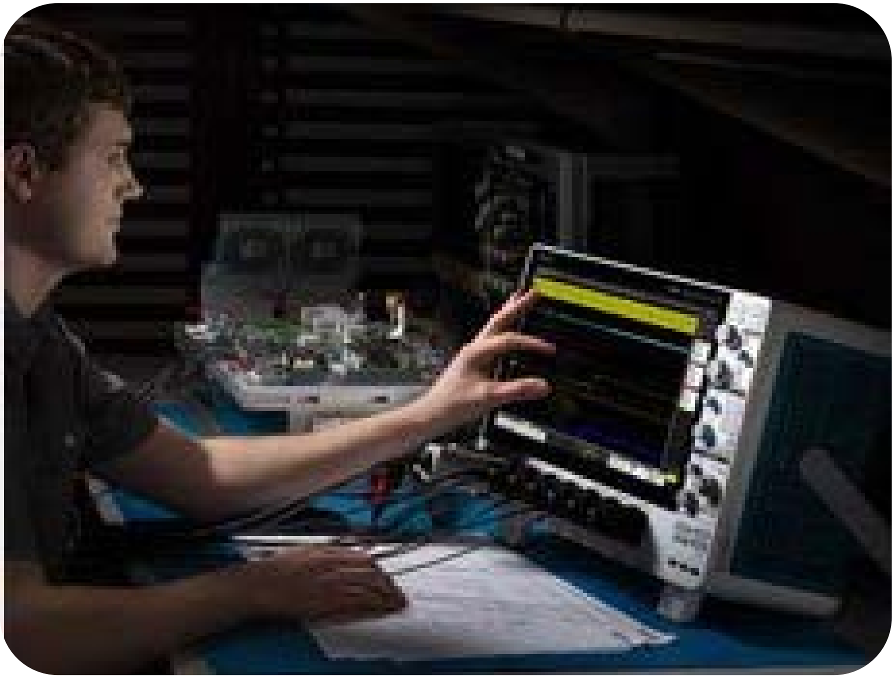
3. I2C trigger: Hex50

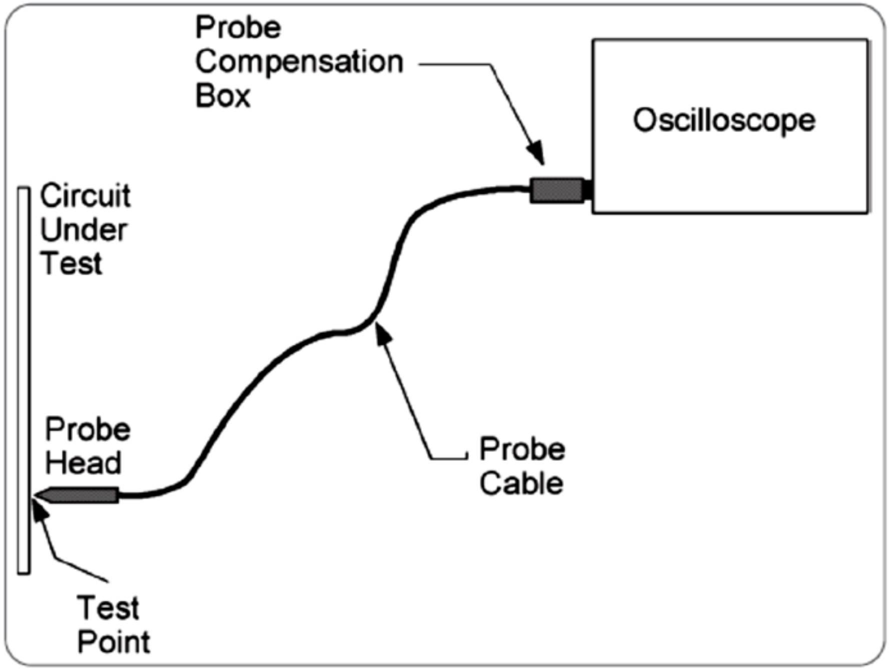
4. Result

Probes

Probes

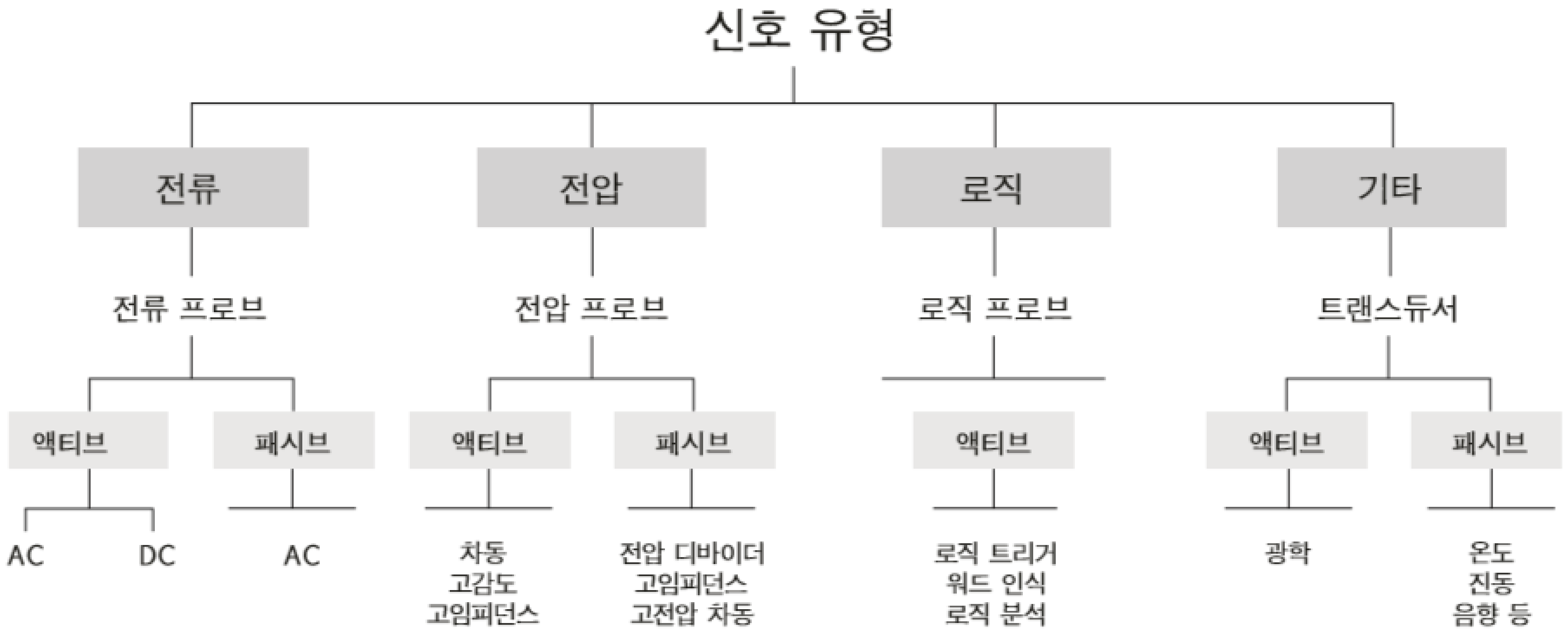
- Vital to your measurement
- Connects your DUT to your oscilloscope
- Affects measurement quality



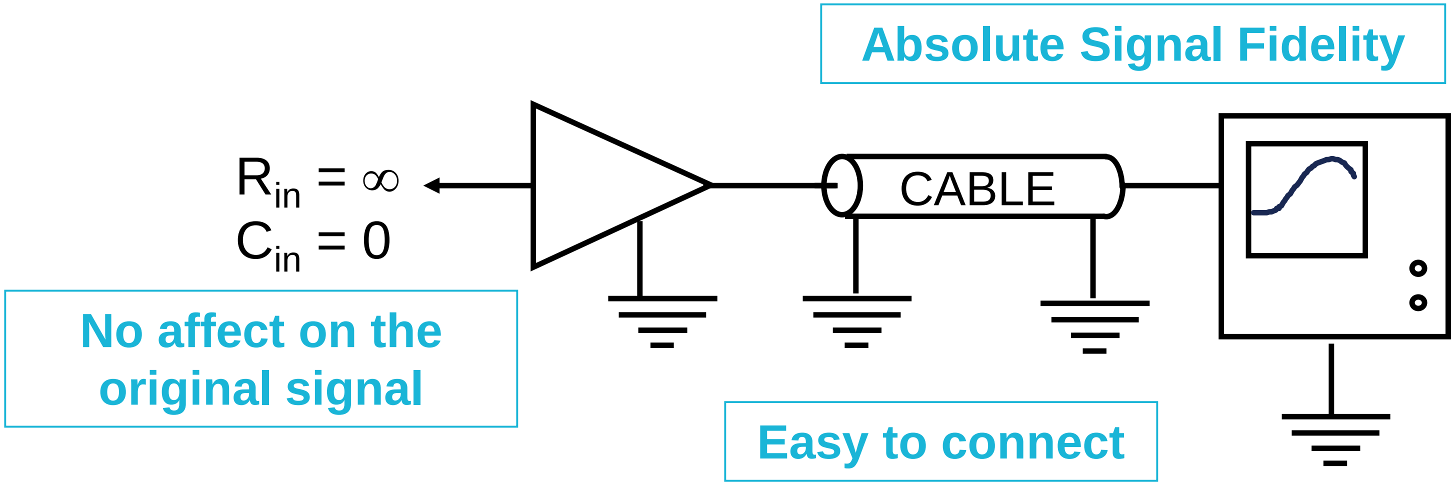


Probes

Probe Types



The Ideal Probe

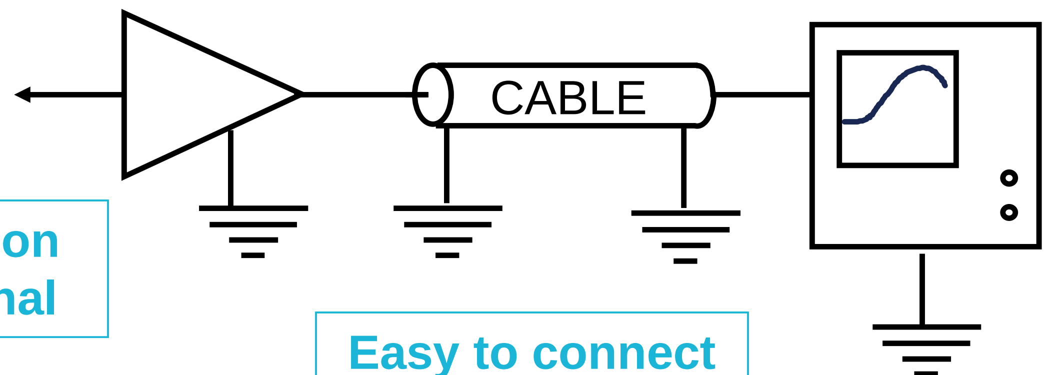


- **No affect on the original signal – *No signal source loading!***
  - Zero Input Capacitance
  - Infinite Input Resistance
- **Absolute Signal Fidelity**
  - Unlimited bandwidth
  - Unlimited rise time
  - Zero attenuation
  - Linear phase across all frequencies
- **A convenient and easy way to connect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

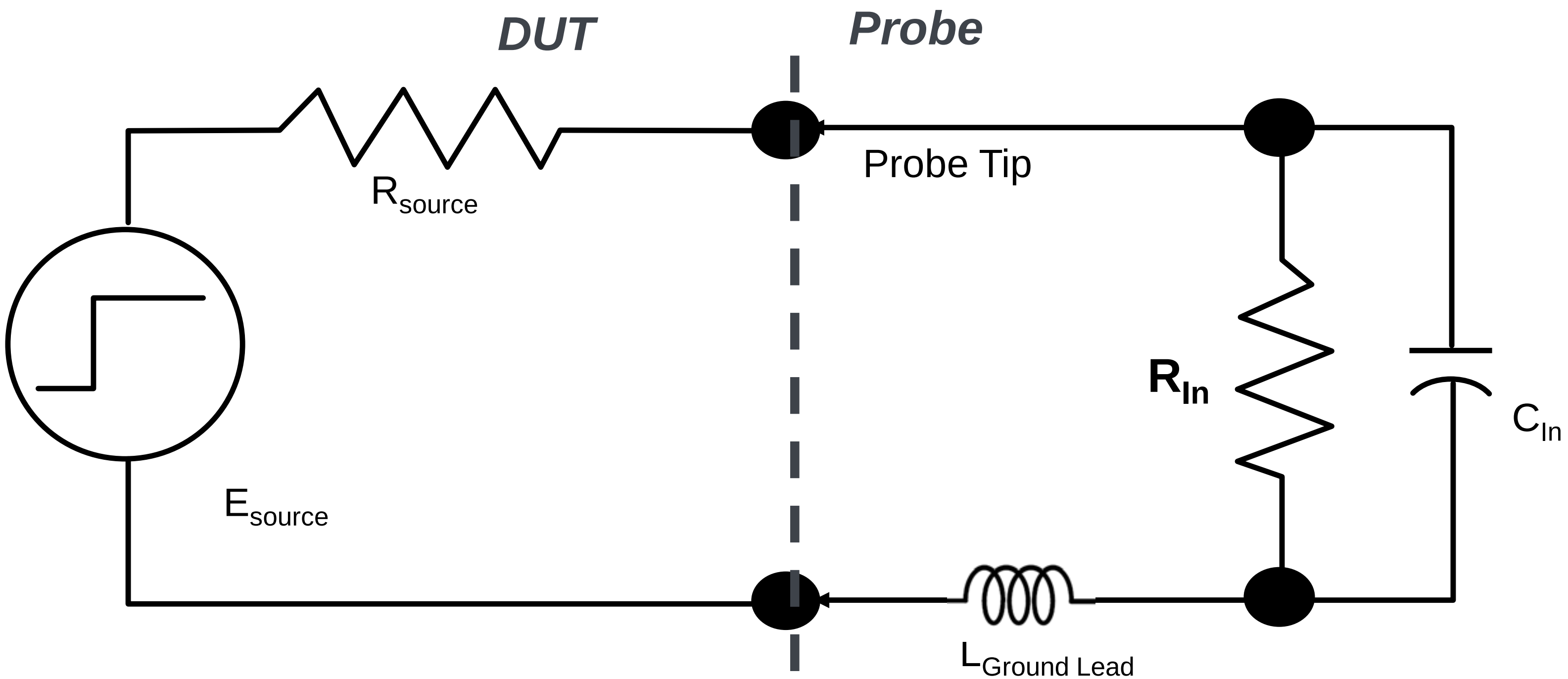
Good Signal Fidelity



Minimize affect on the original signal

Easy to connect

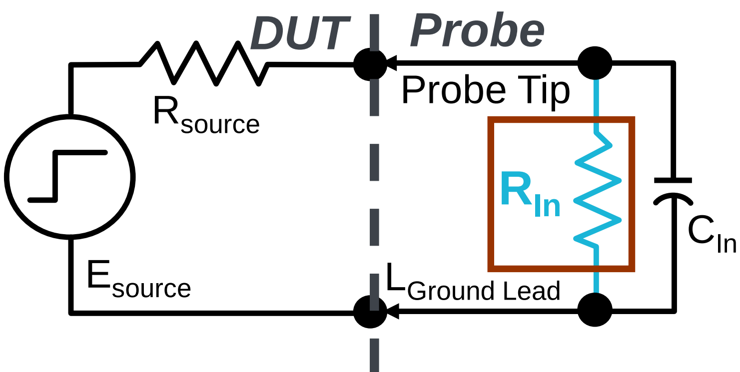
Probe Loading Effect



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

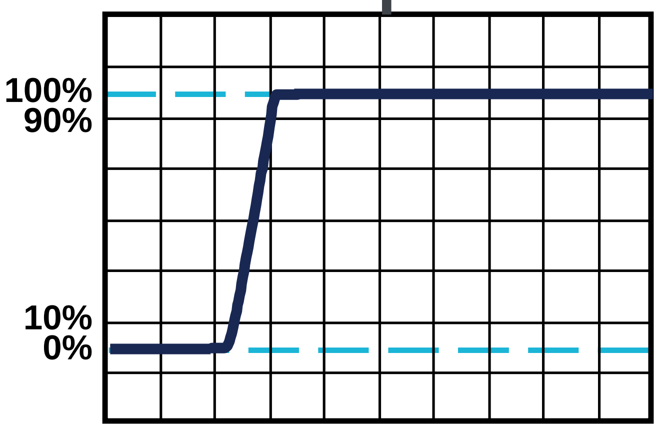
Source Loading – Input Resistance

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

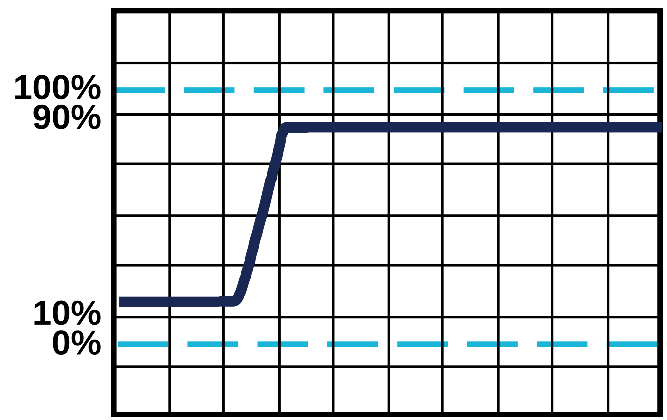


Decreased Signal Amplitude

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



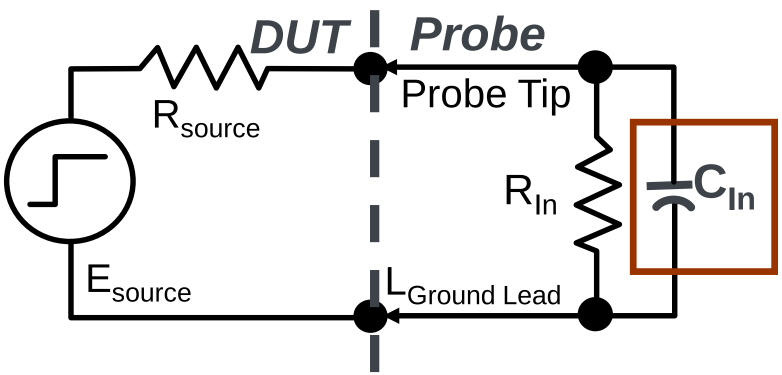
Source Signal



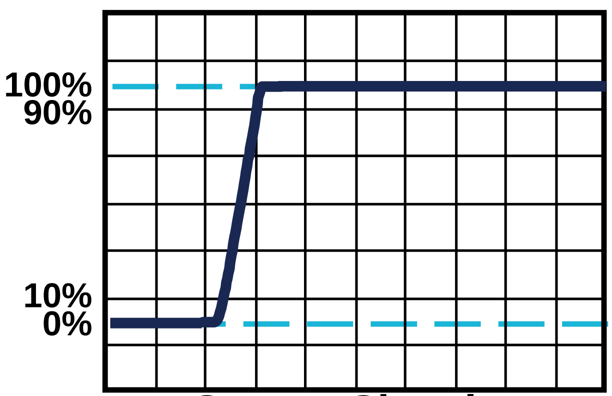
Effects of Input Resistance

Source Loading – Input Capacitance

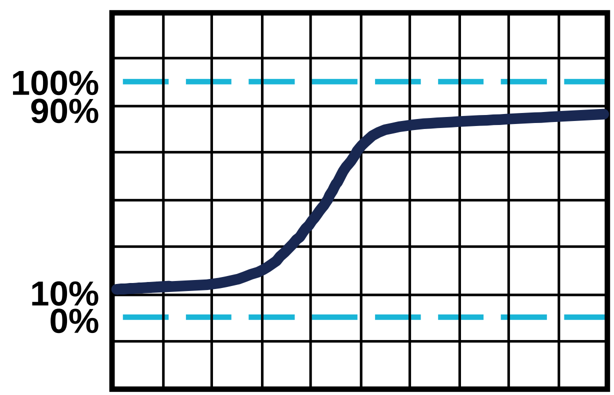
- Smaller input capacitance - higher probe impedance, less loading
- As signal frequency increases, capacitance increases and loading increases



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



Source Signal



Effects of Input Capacitance

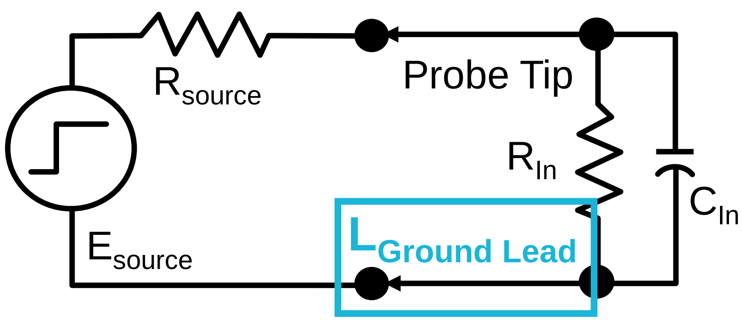
<u>Example:</u>
C_{in} = 100 pF
t_r ~ 220 nsec

C_{in} = 10pF
t_r ~ 22 nsec

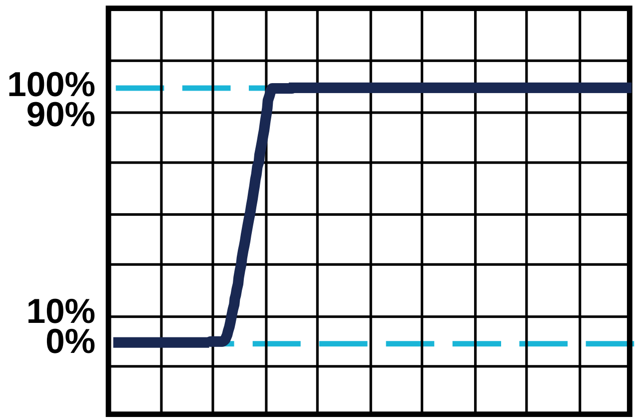
If R_{source} = 1 kΩ

Source Loading - Inductance

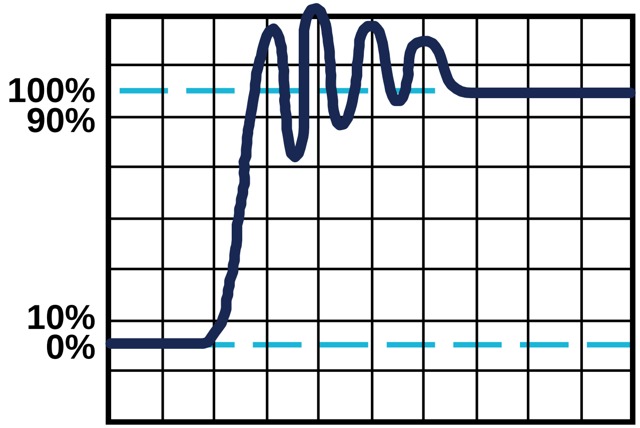
- The longer the ground lead, the higher the probe inductance.
- Keep ground leads as short as possible to avoid ringing!



Resonance (Ringing)



Source Signal

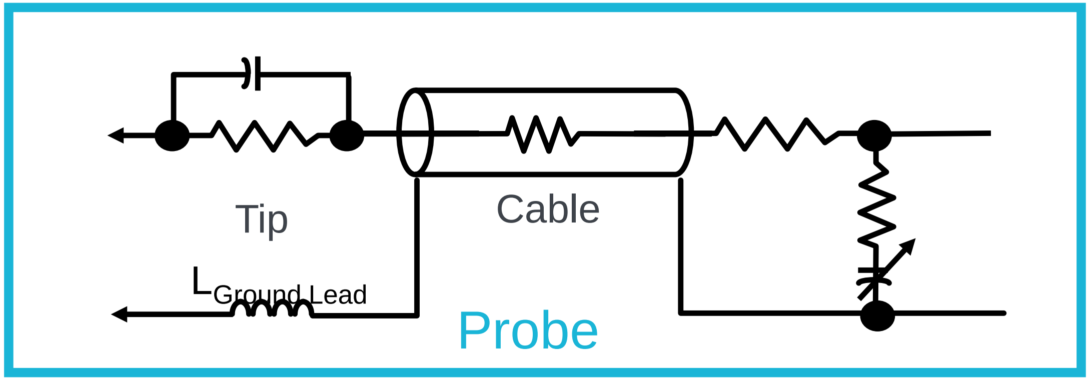


Effects of Inductance

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

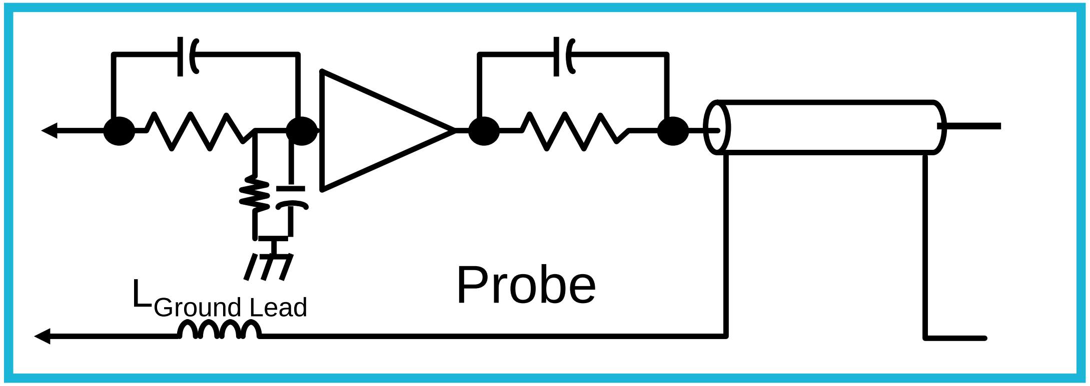
Tektronix TPP1000 Probe
1/10X, ***1GHz***



Active Voltage Probes: Single-Ended

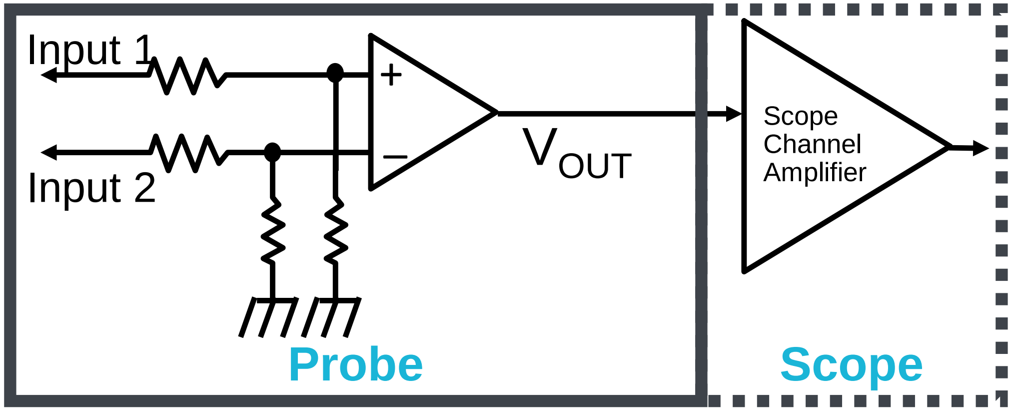
- Uses active components
- Advantages
  - Low Input C
  - Wide Bandwidth
  - High Input R
  - Better Signal Fidelity
- Disadvantages
  - Higher Cost
  - Limited Dynamic Range
  - Mechanically Less Rugged

Tektronix TAP1500
Active Voltage Probe
10X, 1.5 GHz



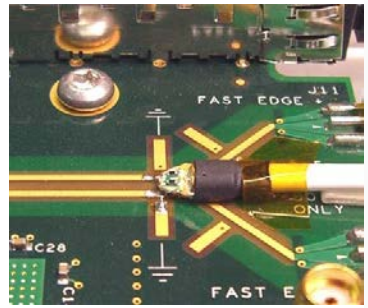
Active Voltage Probes: Differential

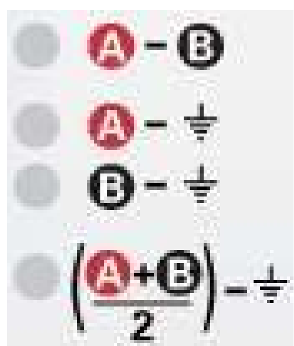
- Differential Probes measure signals that are referenced to each other instead of earth ground.
- Advantages
  - Wide bandwidth
  - Large Common Mode Rejection Ratio (CMRR)
  - Minimal skew between inputs
  - Small input capacitance

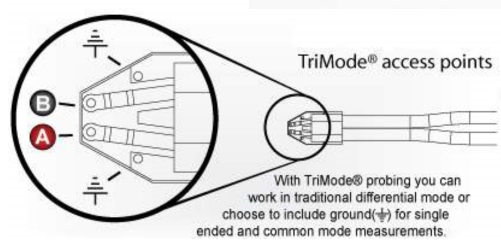


Tektronix P7700 Series TriMode Differential Probe

TriMode™ P7500/P7700 Series Probe

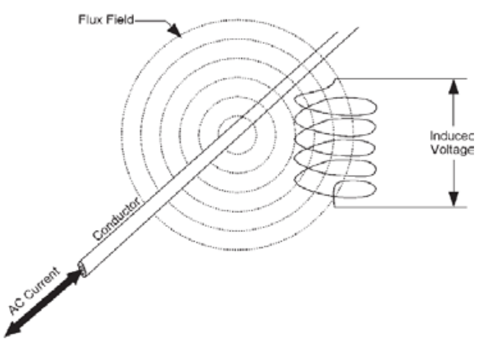






Current Probes

- 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

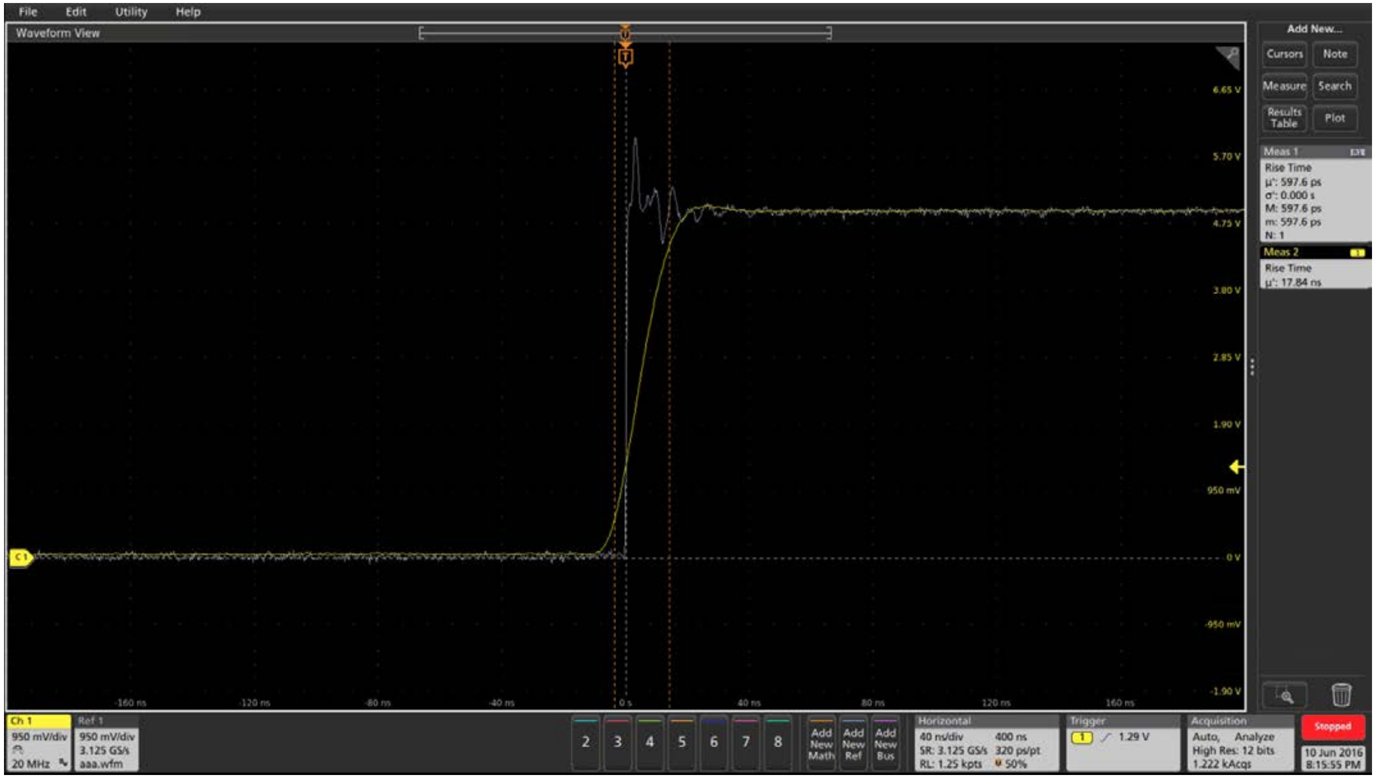
- **TEKPROBE Level 1 BNC Probes**

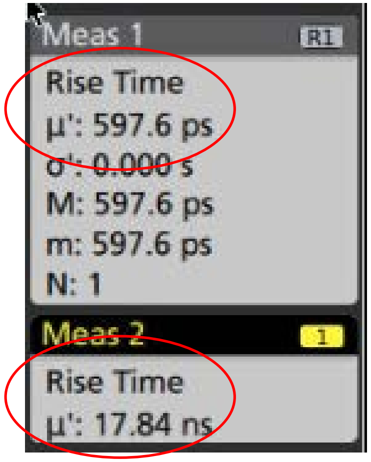
- **TEKPROBE Level 2 BNC Probes**

- **TekVPI Probes**
  TekVPI probe connection is

- **TekConnect Probes**
  Probes with our TekConnect

How bandwidth affects the waveform

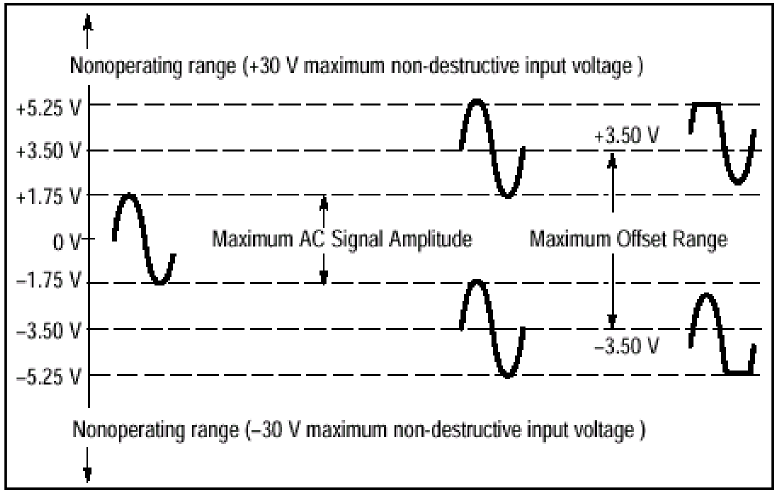




Ch1: 1GHz full Bandwidth
Ref1: 20MHz Cutoff

Voltage Window, Dynamic Range & Offset

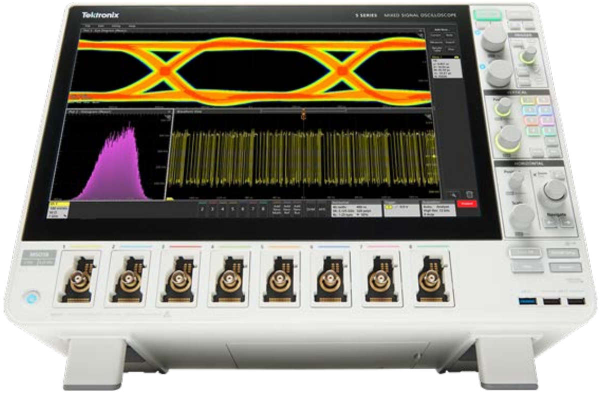
- Operating Voltage Window
  - Maximum voltage applied without Saturation
  - Incorrect Voltage Window Produces Measurement Errors
- Dynamic Range
  - Newer active probes designed around lower voltage level
  - Multiple D.R Select with trade off noise
- DC Offset
  - Positioning Of The Signal to the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



Hands-on Lab:#6

Understanding Probe loading effect

- **Probe Calibration**



FastAcq(DPX)

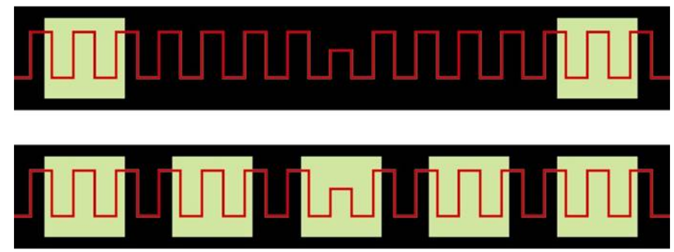
FastFrame

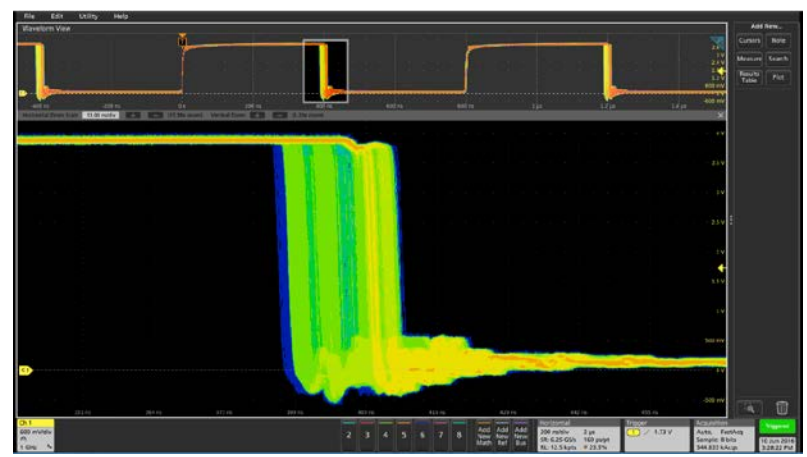
Vertical Resolution (Noise)

Spectrum View

Going Beyond Basic Signal Visualization

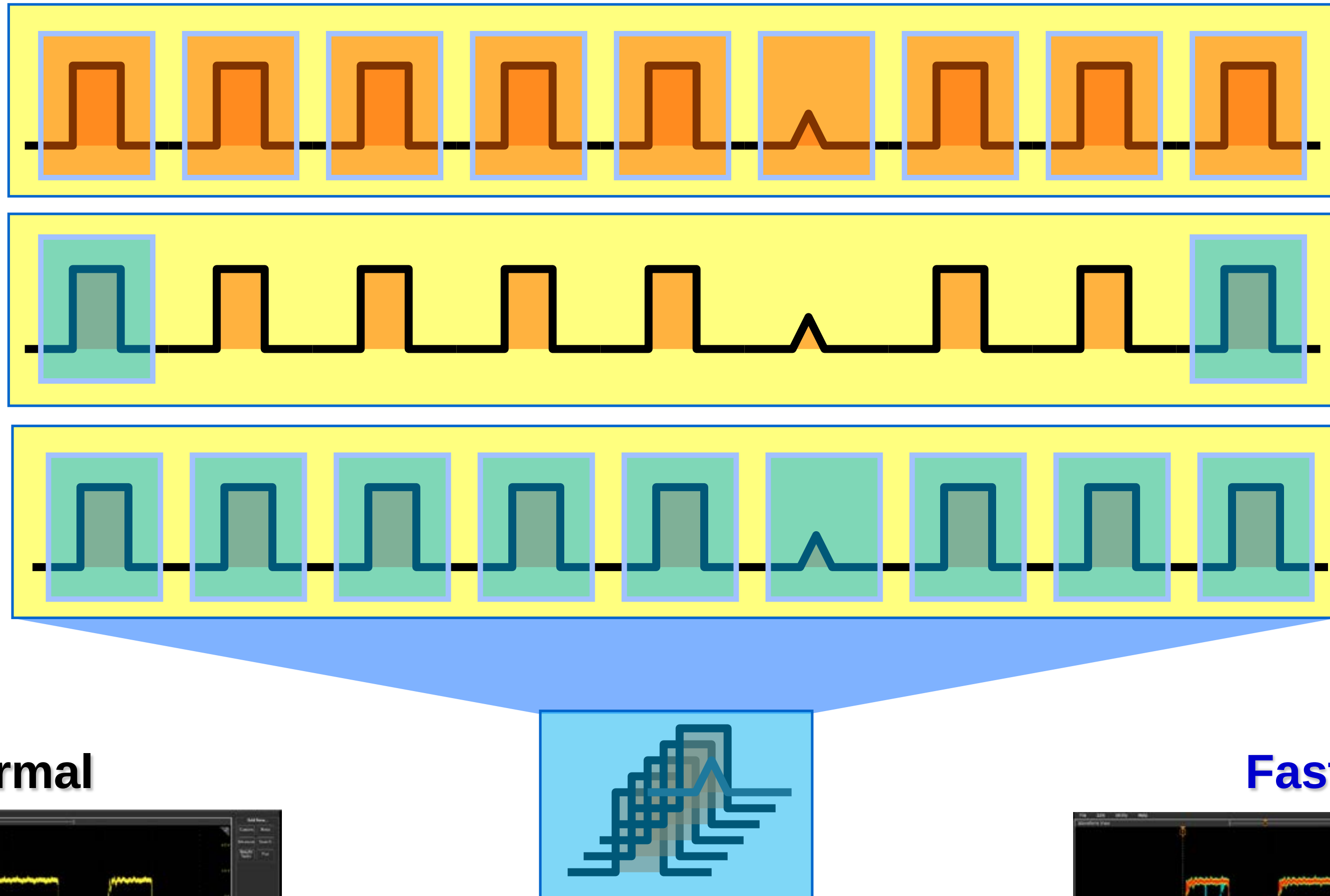
- **Oscilloscope Dead time related to Fast waveform capture rate**
  - How fast a scope can acquire and display data
  - Faster capture rate means you'll find elusive glitches and other transient events faster





- **Digital phosphor display with intensity-grading**
  - Shows frequency of occurrence for better characterizing failures

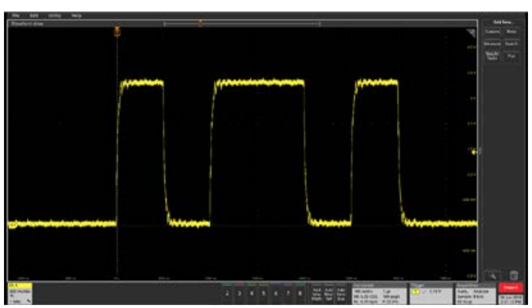
FastAcq. – DPX Technology



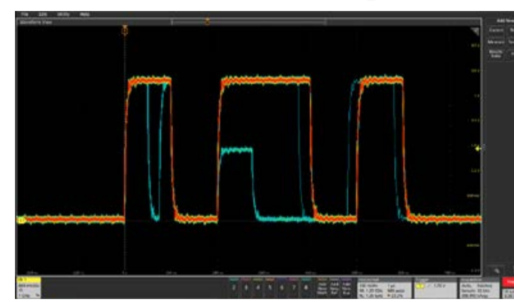
Digital Storage
(Normal)

FastAcq

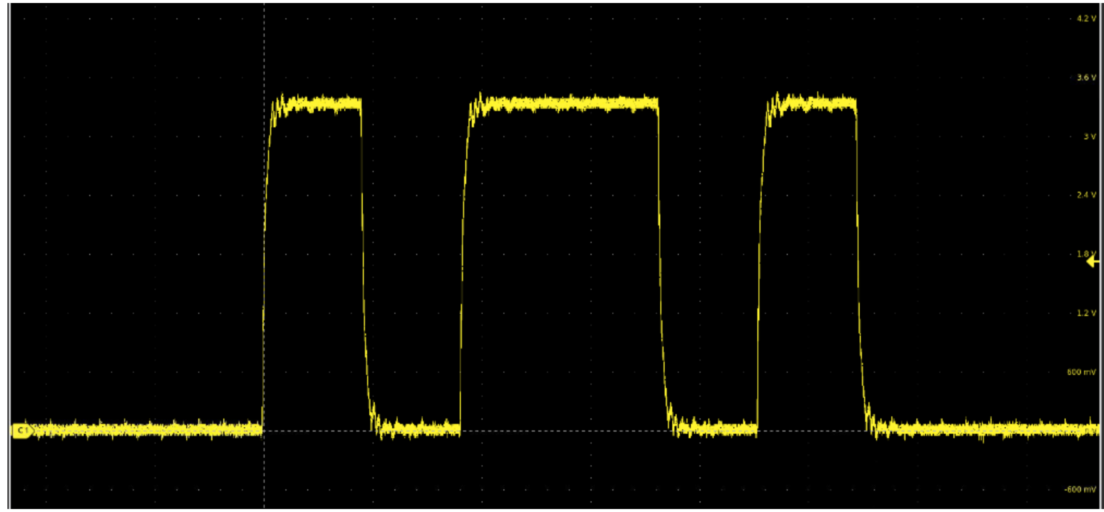
Normal

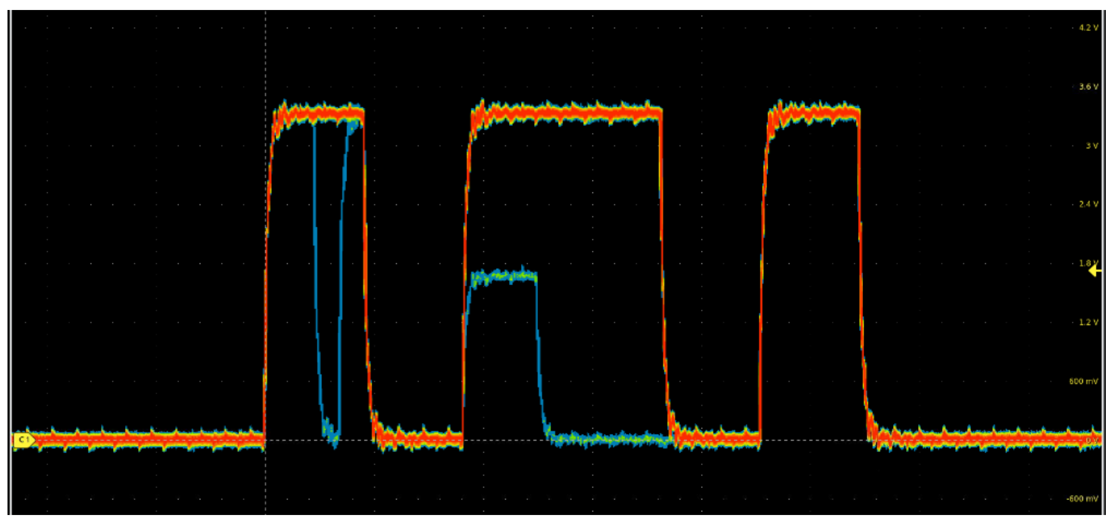


FastAcq



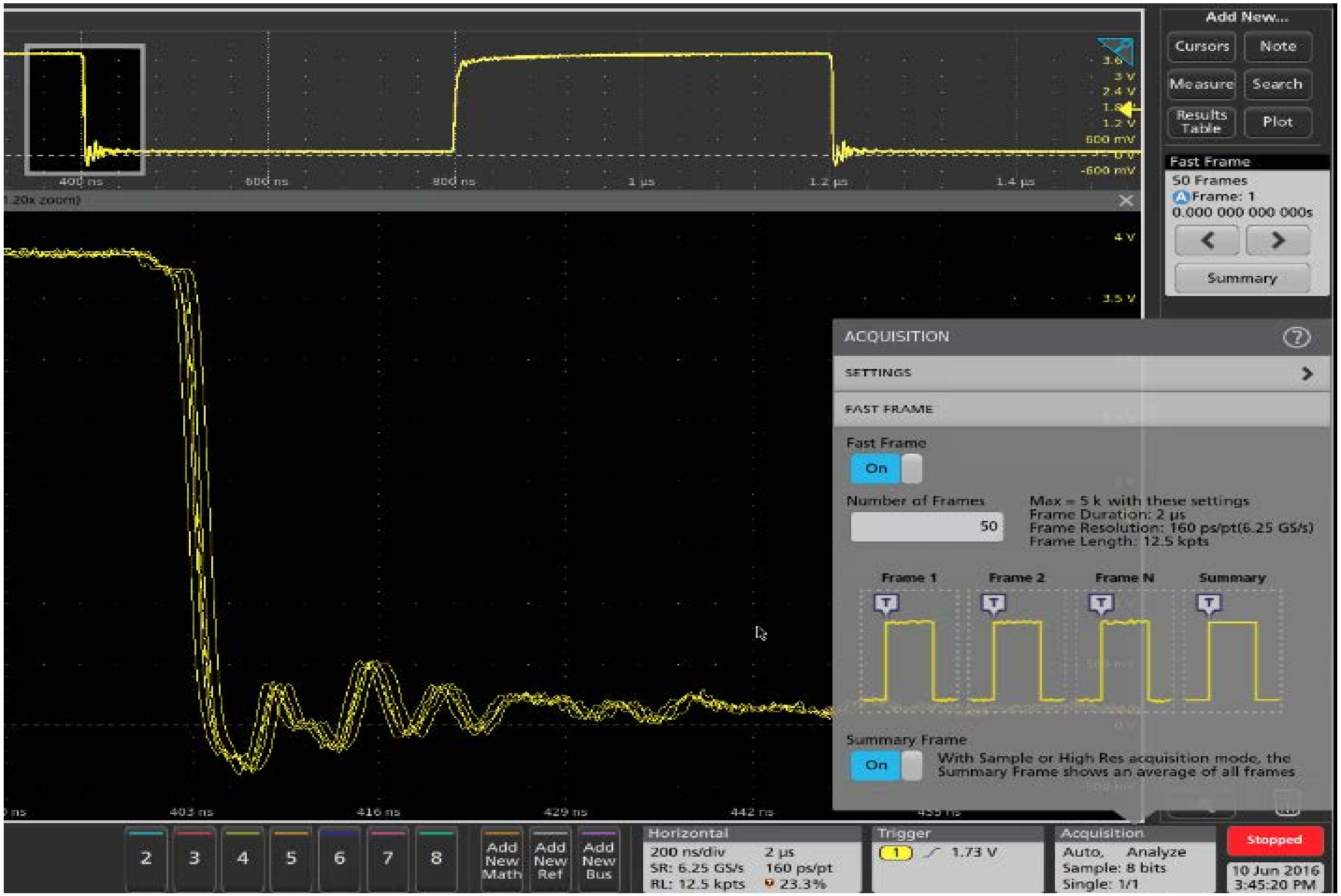
FastAcq. – DPX Technology





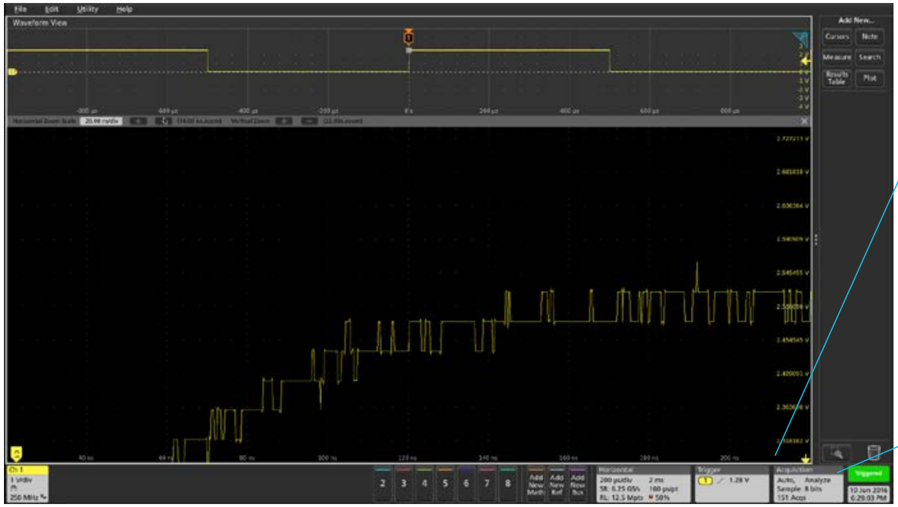
Fast Frame Mode

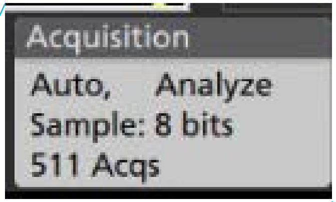
- Effective memory utilization for debugging

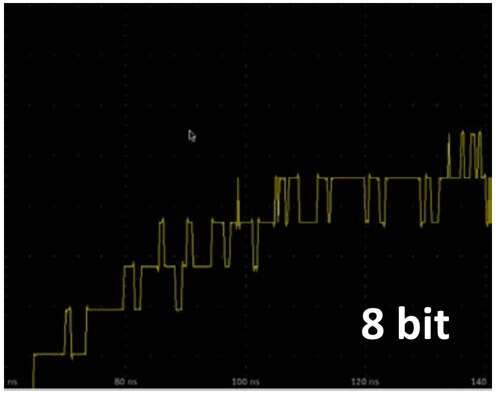


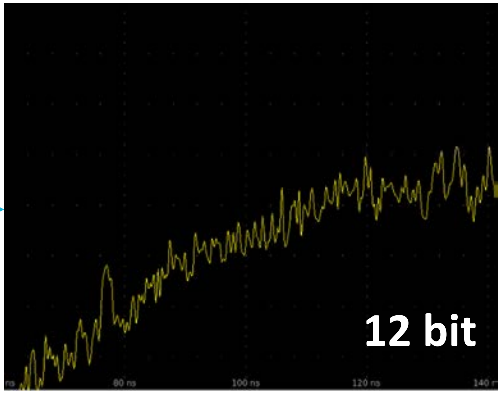
12 bit Resolution and HighRes mode

Advantage of 12 bit (Max 16bit) Vertical Resolution

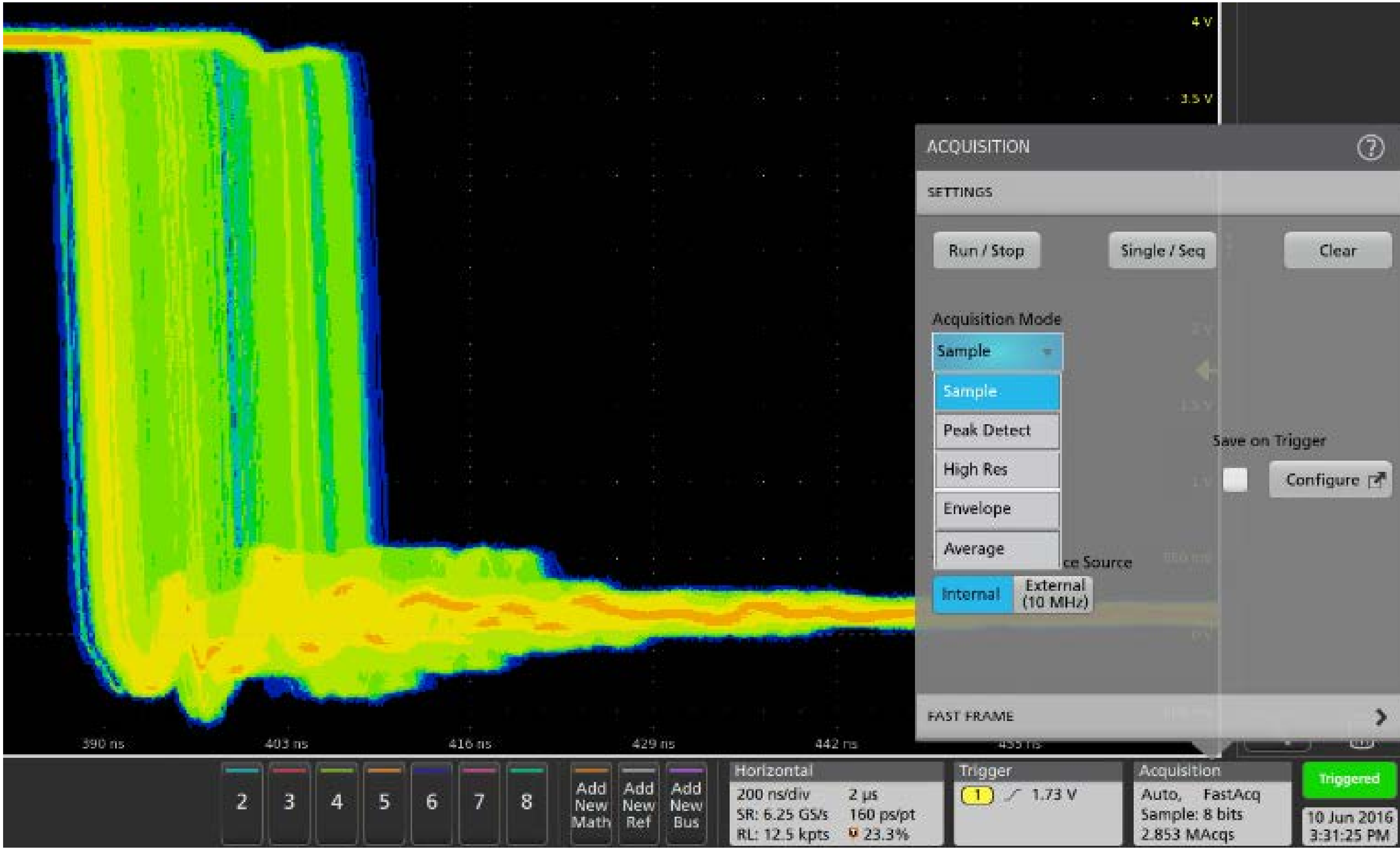






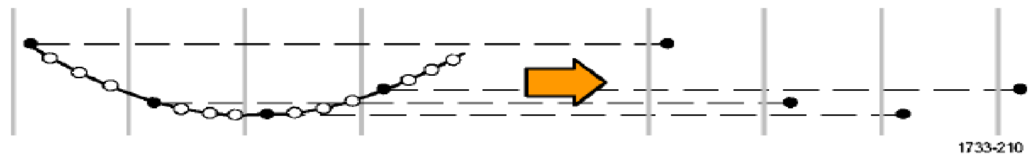


Hori/Acq - Acquisition Setup

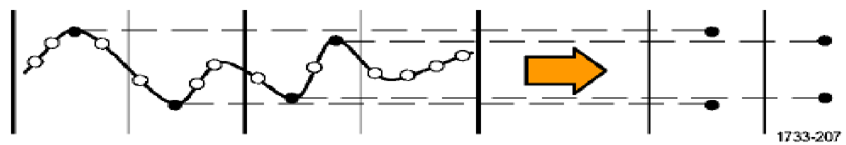


Hori/Acq - Aquisition Mode

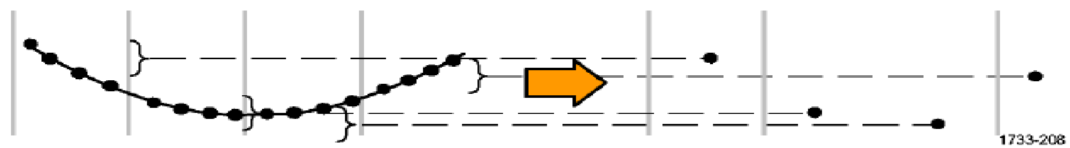
샘플 모드는 각 획득 간격에서 첫 번째 샘플링된 포인트를 유지합니다. 샘플은 기본 모드입니다.



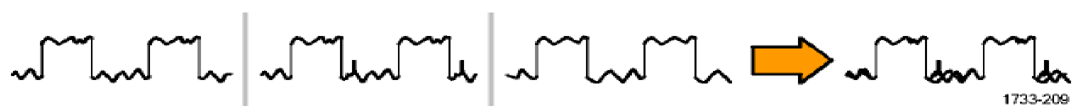
피크 검출 모드는 두 개의 연속적인 획득 간격에 포함된 모든 샘플 중에서 최대값과 최소값을 사용합니다. 이 모드는 보간되지 않는 실시간 샘플링에서만 작동하며 높은 주파수 글리치를 찾는 데 유용합니다.



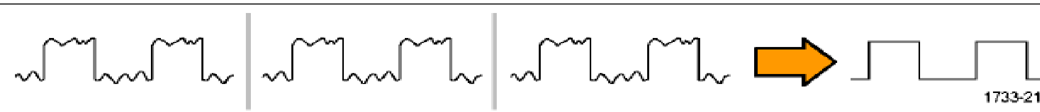
Hi-Res 모드는 각 획득 간격에서 모든 샘플의 평균을 계산합니다. Hi-Res는 고해상도, 저대역폭 파형을 제공합니다.



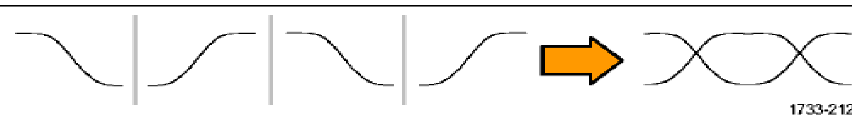
엔벨로프 모드는 많은 획득 중에서 최고 및 최저 레코드 포인트를 찾습니다. 엔벨로프는 각 개별 획득을 위해 피크 검출을 사용합니다.



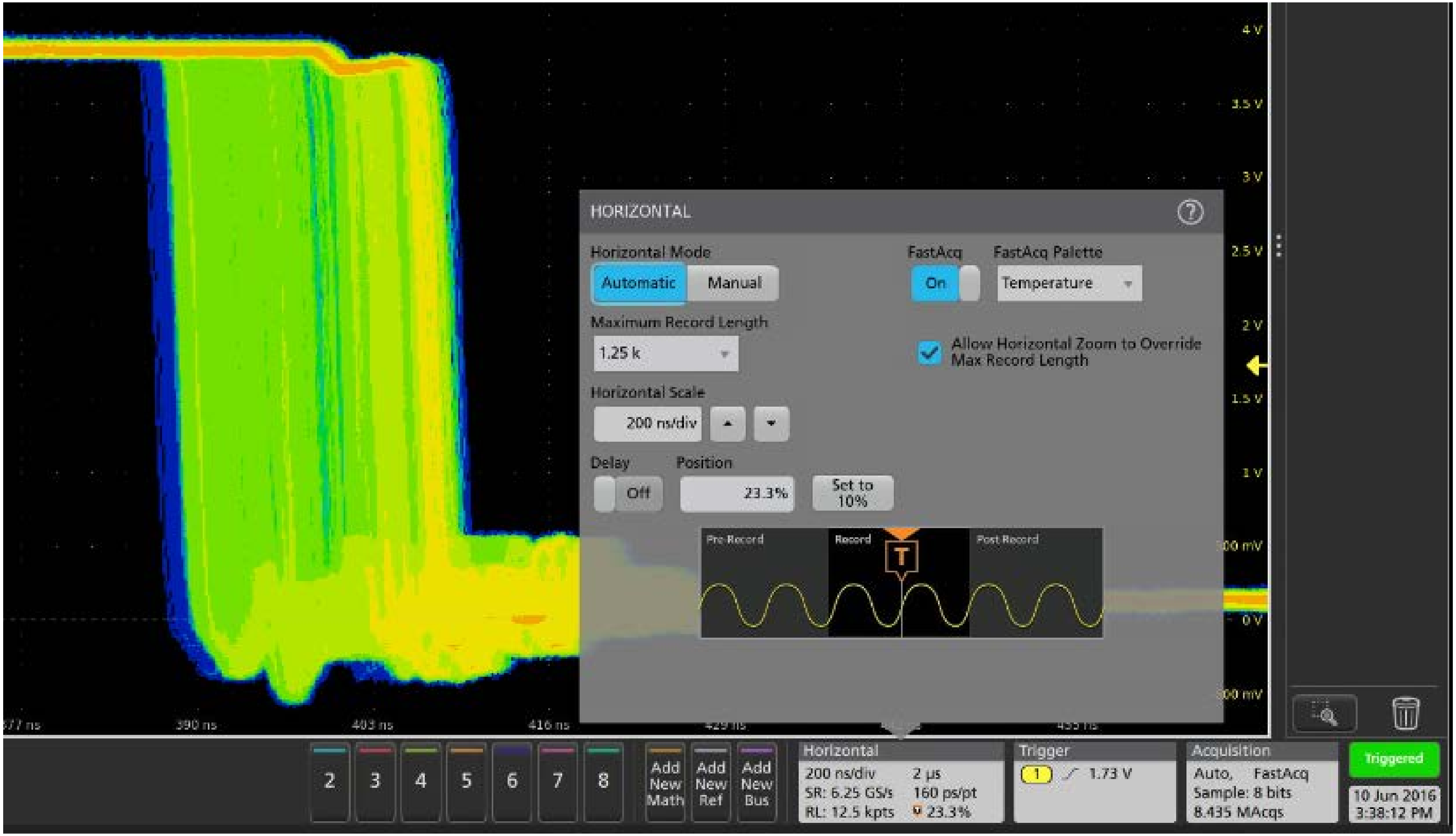
평균 모드는 많은 획득 중에서 각 레코드 포인트에 대해 평균 값을 계산합니다. 평균은 각 개별 획득에 대해 샘플 모드를 사용합니다. 랜덤 노이즈를 줄이려면 평균 모드를 사용하십시오.



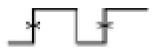
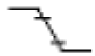
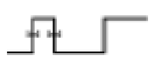
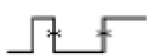
파형 데이터베이스 모드는 여러 획득에 대한 소스 파형 데이터의 3차원 누적입니다. 데이터베이스에는 진폭 및 타이밍 정보뿐 아니라 특정 파형 포인트(시간 및 진폭)를 획득한 횟수가 포함됩니다.



Hori/Acq - Horizontal Setup



Measurement – Time measurement

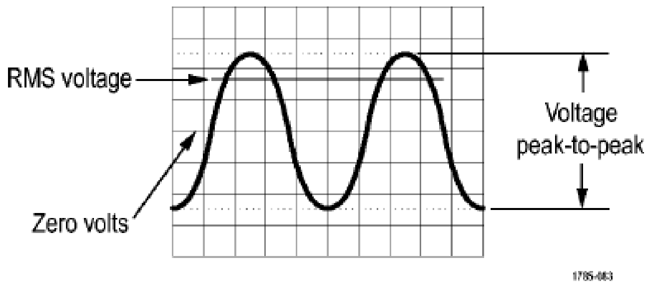
Frequency		The first cycle in a waveform or gated region. Frequency is the reciprocal of the period; it is measured in hertz (Hz) where one Hz is one cycle per second.
Period		The time required to complete the first cycle in a waveform or gated region. Period is the reciprocal of frequency and is measured 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

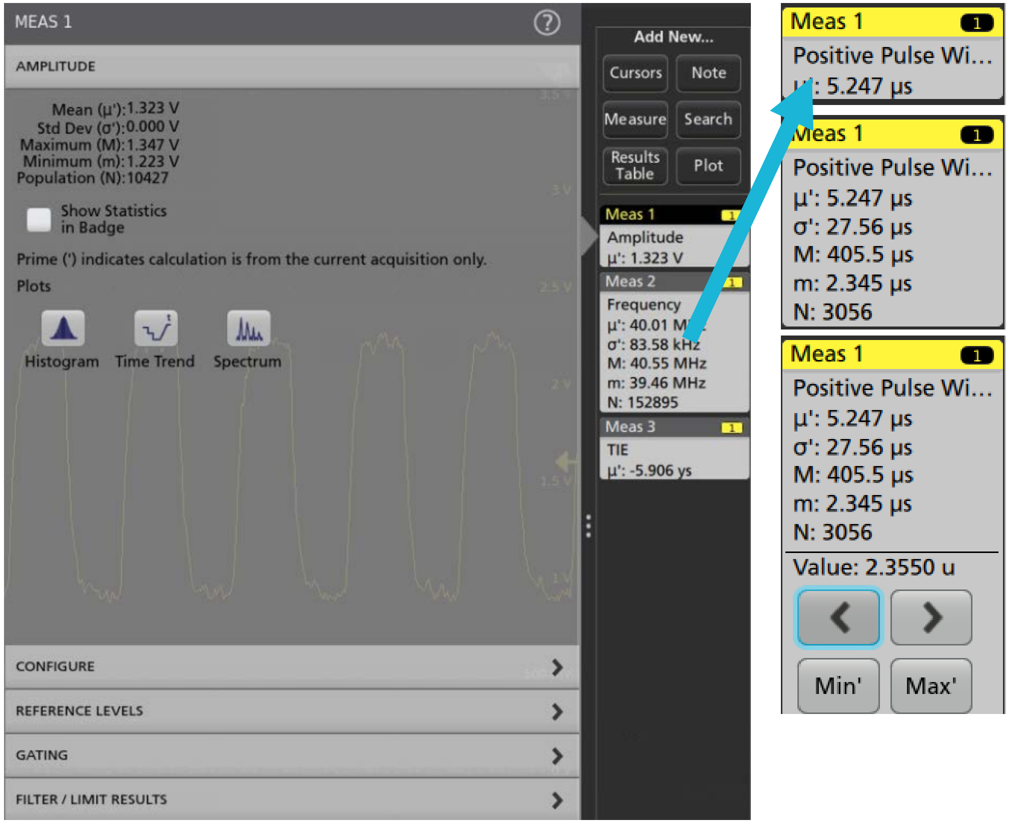
Measurement	Description
Mean	The arithmetic mean over the entire waveform or gated region.
Cycle Mean	The arithmetic mean over the first cycle in the waveform or the first cycle in the gated region.
RMS	The true Root Mean Square voltage over the entire waveform or gated region.
Cycle RMS	The true Root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



Measurement

MEASUREMENT AND RESULTS BAR

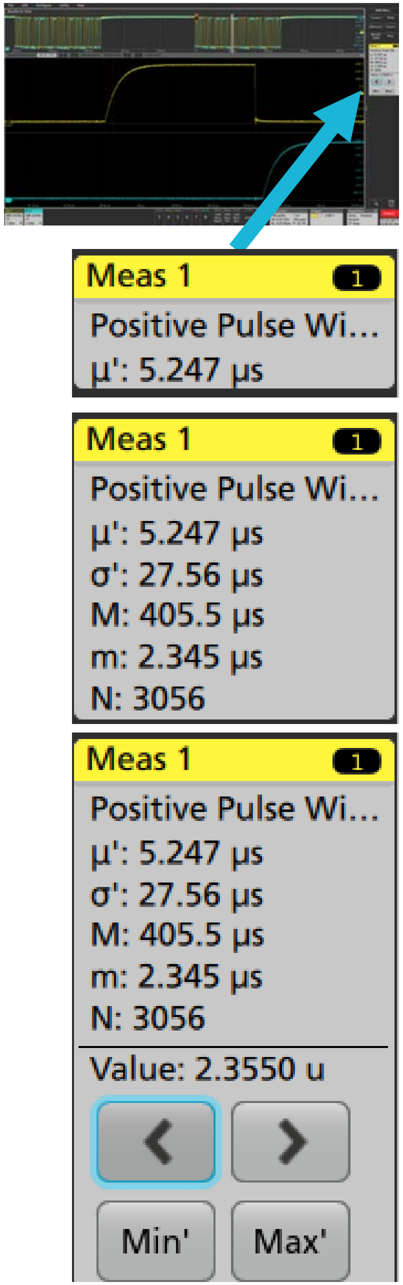
- **Single tap** to Add New..
  - Plots
  - Search
  - Measurements
  - Notes
  - Cursors
  - Results Table
- **Double tap** badges to access measurement configure
  - Easily add measurement plots
  - Turn on statistics
  - Local or Global reference levels
  - Local or Global gating parameters



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



Spectrum View

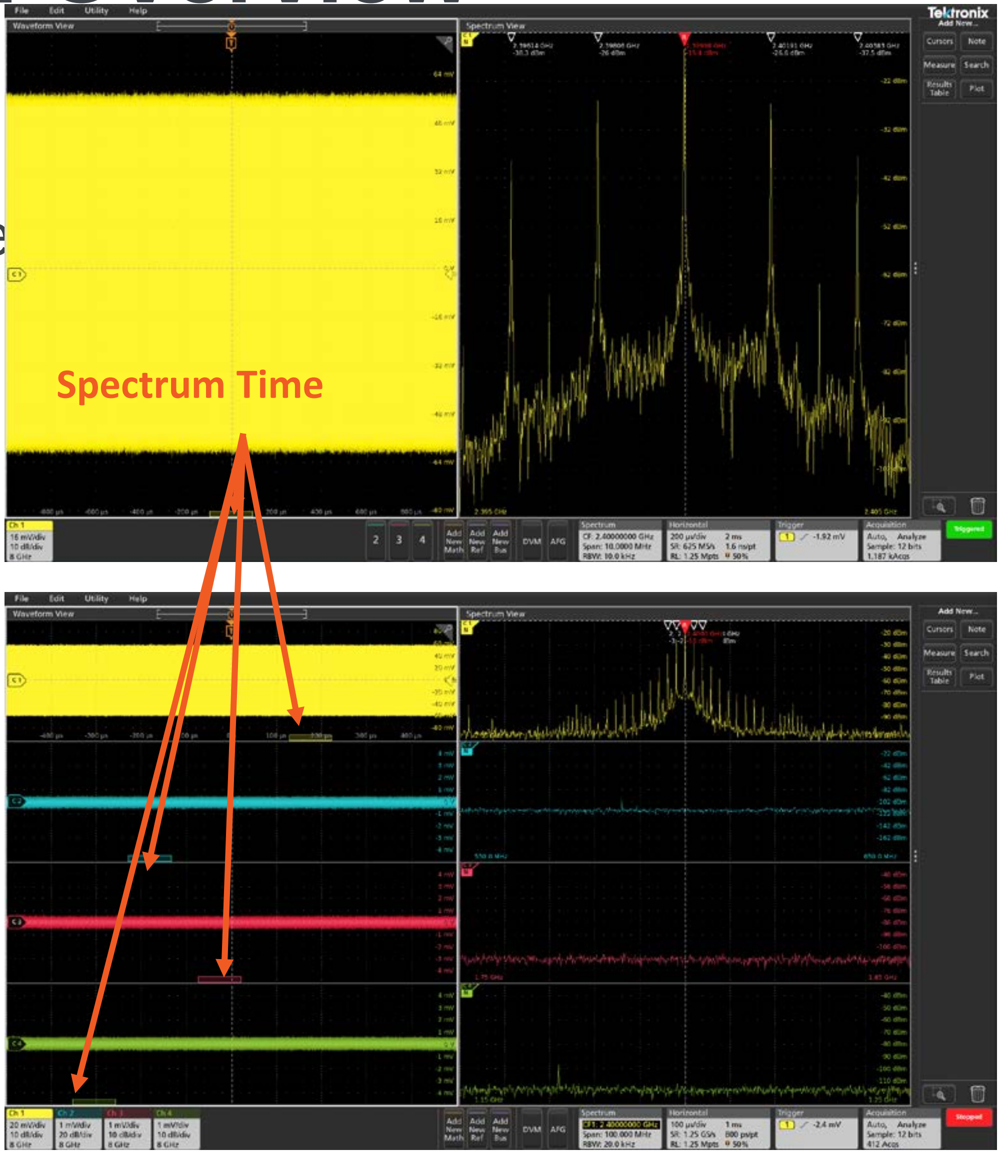
THE ULTIMATE IN FREQUENCY DOMAIN ANALYSIS ON A SCOPE

- Patented acquisition technology provides independent controls in each domain
  - Far easier to setup frequency domain view than any regular FFT
  - Enables you to achieve the desired view in each domain
- Spectrum Time makes it easy to:
  - Observe how the frequency domain view changes over time.
  - Correlate frequency domain events with time domain signals/events of interest.

Spectrum View UI Overview

SPECTRUM TIME

- Spectrum Time shows where in time, the spectrum being viewed came from
- Can navigate spectrum time throughout the acquisition
  - Front panel pan control
  - Dragging the indicator

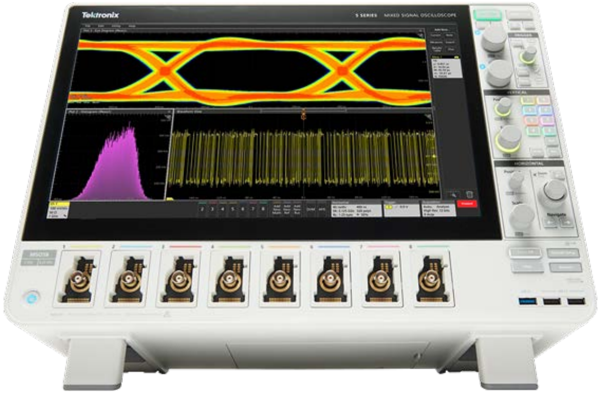


Hands-on Lab:#7

FastAcq
FastFrame
12bit Vertical Resolution

Horizontal/Acquisition Setting
Measurement

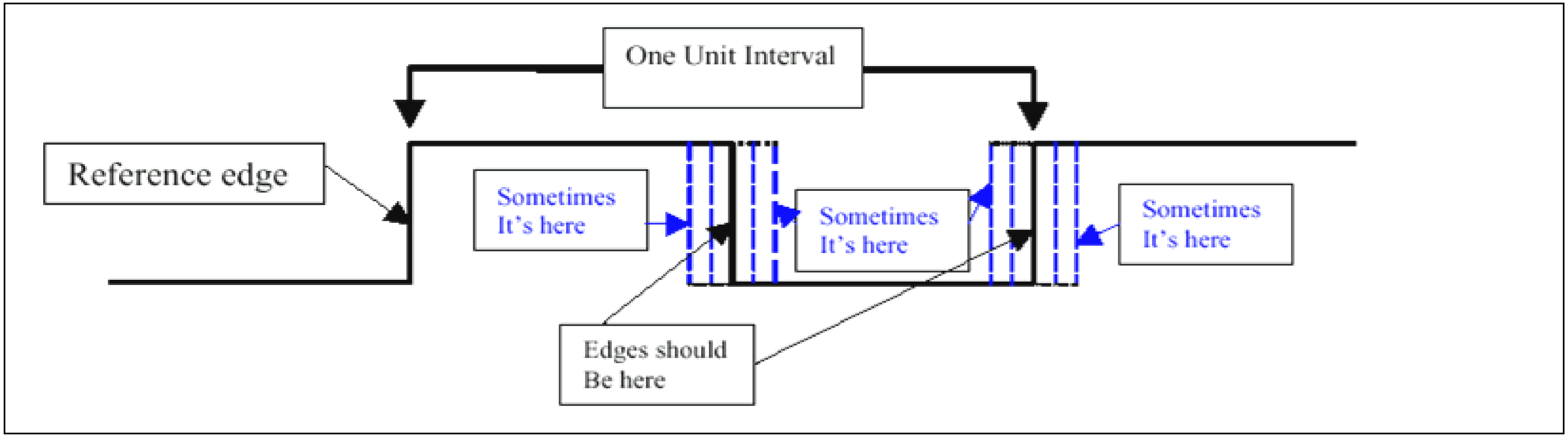
Spectrum View



Jitter Fundamentals

What is Jitter?

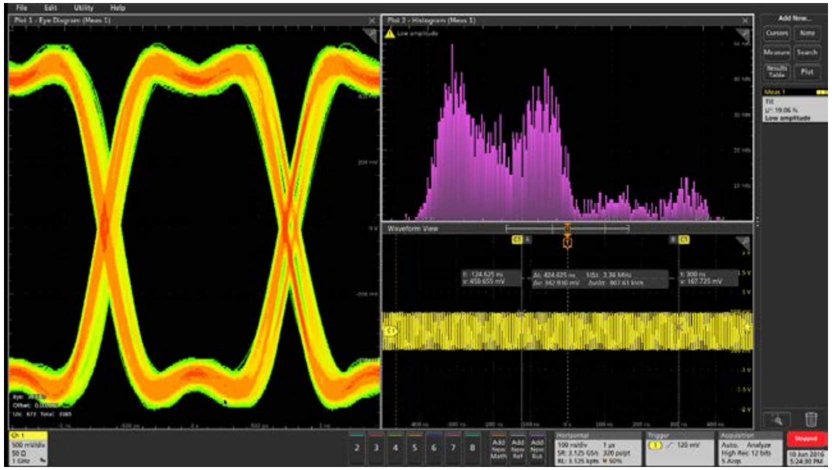
- Definitions
  - "The deviation of an edge from where it should be"
  - ITU* Definition of Jitter: "Short-term variations of the significant instants of a digital signal from their ideal positions in time"

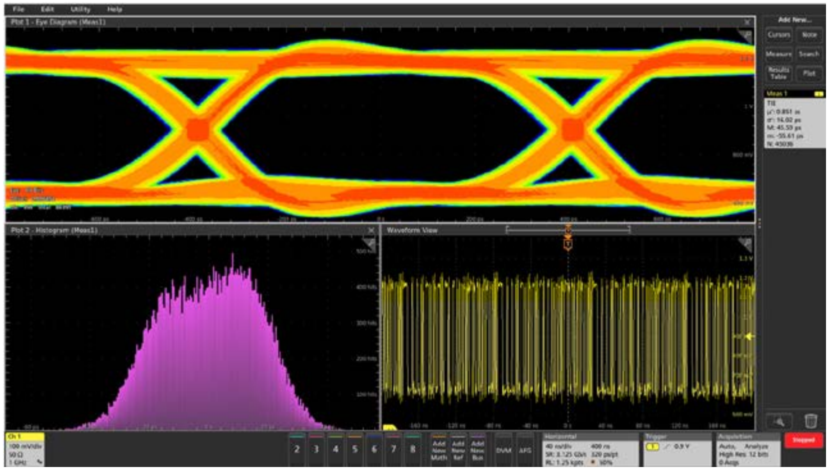


* ITU : International Telecommunication Union

Jitter is caused by many things

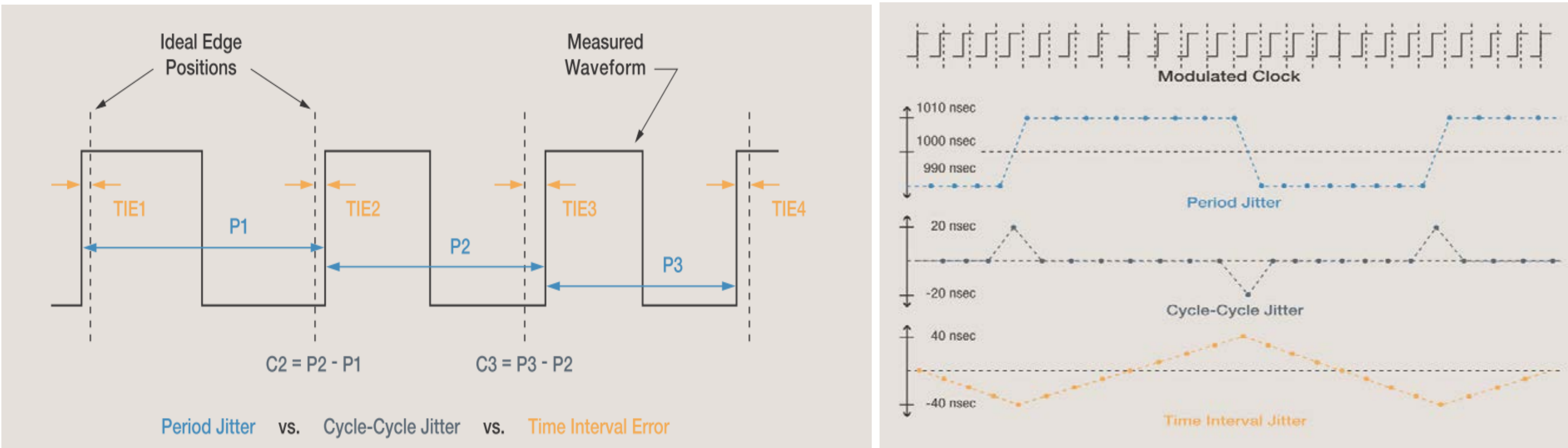
- Causes of Random Jitter(RJ)
  - Thermal noise
    - Generally Gaussian
    - External radiation sources
    - Like background conversations…random and ever changing
- Causes of Periodic Jitter(PJ)
  - Injected noise (EMI/RFI) & Circuit instabilities
    - Usually a fixed and identifiable source like power supply and oscillators
    - Will often have harmonic content
    - Transients on adjacent traces
    - Cabling or wiring (crosstalk)
  - PLL’s problems
    - Loop bandwidth (tracking & overshoot)
    - Deadband (oscillation / hunting)
- Causes of Data Dependent Jitter(DDJ)
  - Transmission Losses
    - There is no such thing as a perfect conductor
    - Circuit Bandwidth
    - Skin Effect Losses
    - Dielectric Absorption
    - Dispersion – *esp. Optical Fiber*
    - Reflections, Impedance mismatch
    - Path discontinuities (connectors)





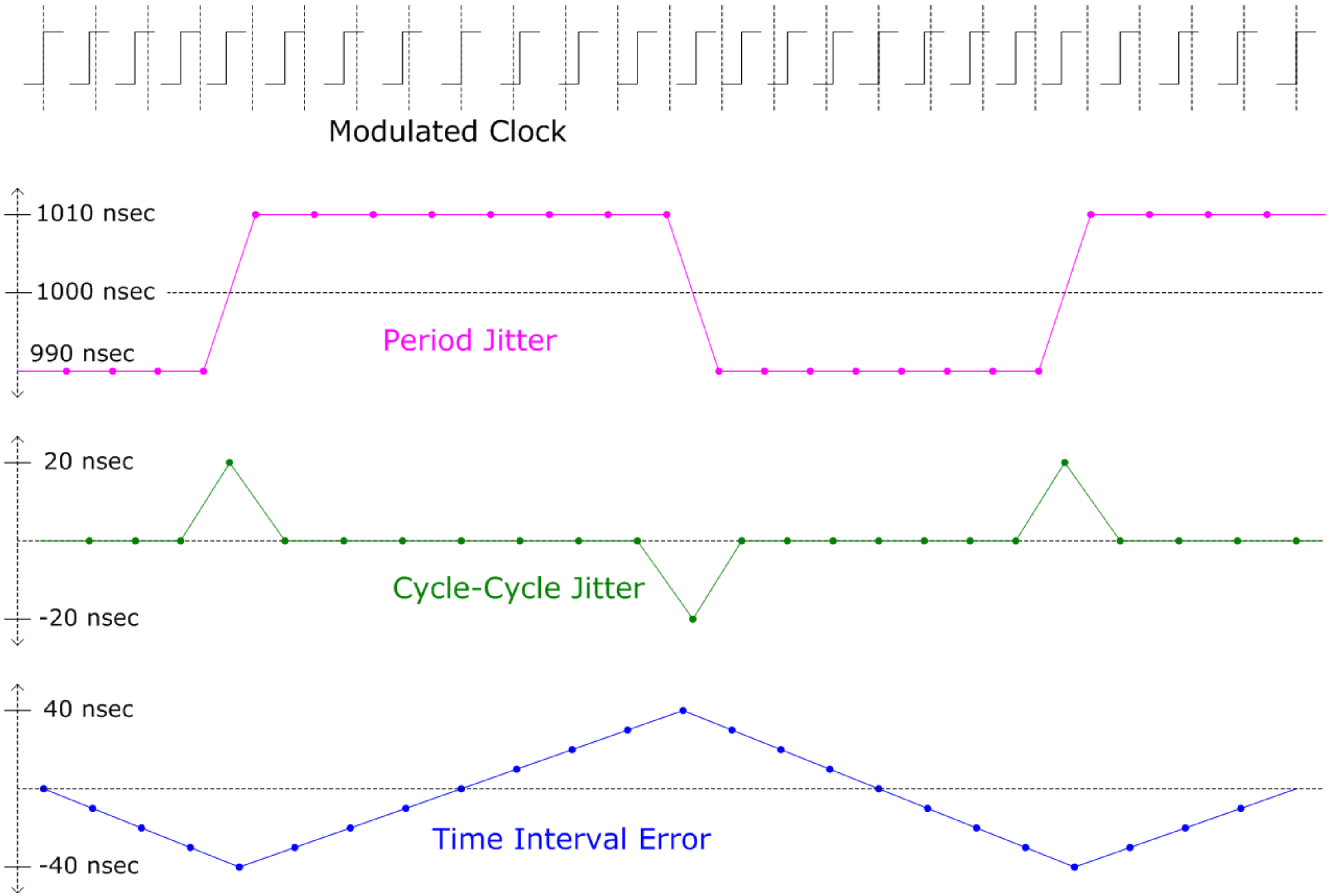
What is the Jitter ?

"Jitter is defined as the short-term variations of a digital signal's significant instants from their ideal positions in time." **(per SONET)**



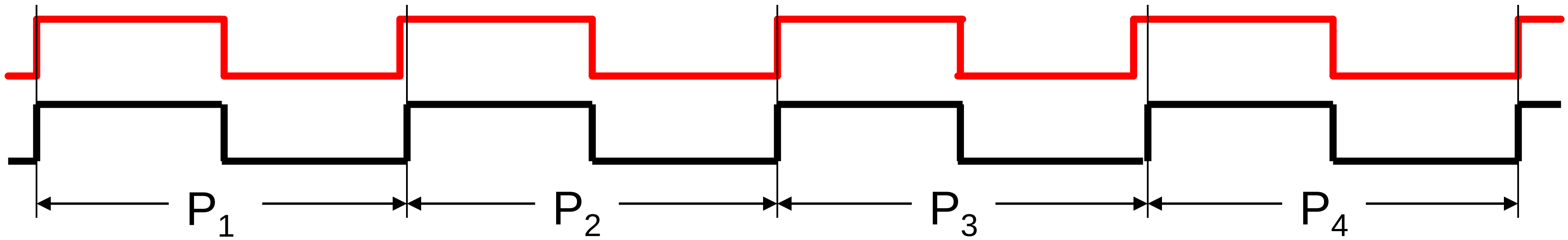
- TIE(Time Interval Error)
  - measure the *Time Interval* from it to an edge of an ref clock, or a PLL.
- Period Jitter
  - $P_n = TIE_n - TIE_{n-1} + K$
- Cycle-to-Cycle Jitter
  - plot just the changes from last period Derivative of Period Jitter
  - Cn = Pn - Pn-1 + K

Types of Jitter (Visualization)



Jitter Measurements

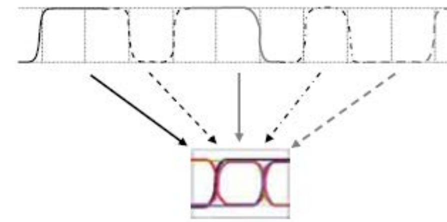
	0.0ns		0.990ns		2.000ns		2.980ns		4.000ns

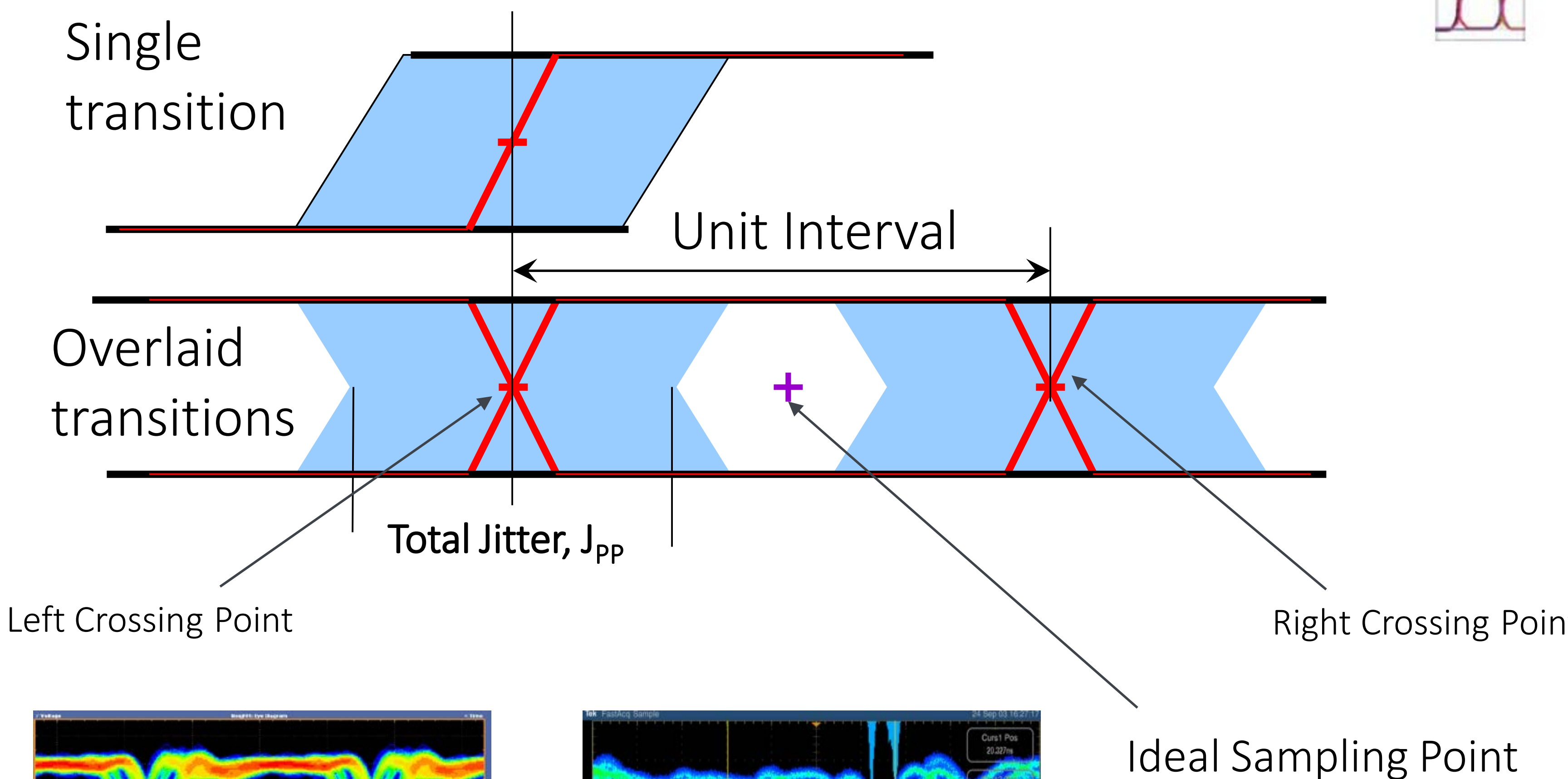


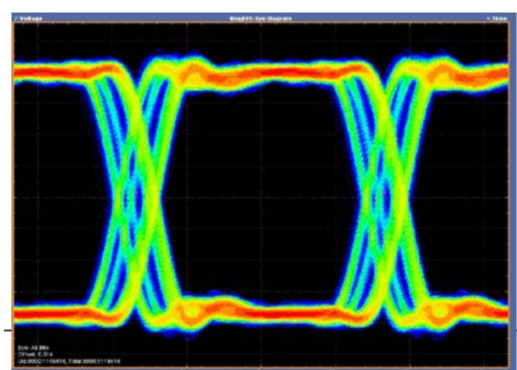
P		0.990ns		1.010ns		0.980ns		1.020ns	
Cy-Cy			0.020ns		-0.030ns		0.040ns		
TIE			-0.010ns		0.000ns		-0.020ns		0.000ns

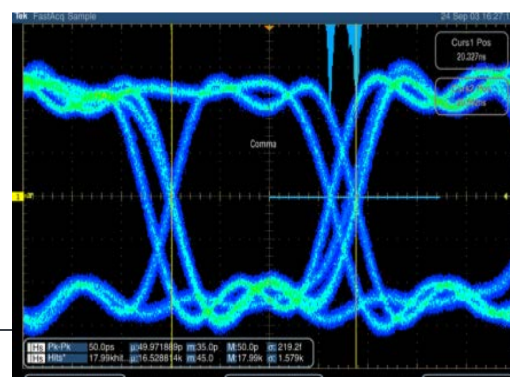
Period Jitter	= 18.3ps StdDv	(0.990/1.010/0.980/1.020)
Cy-Cy Jitter	= 36.1ps StdDv	(0.020/-0.030/0.040)
TIE	= 9.6ps StdDv	(-0.010/0.000/-0.020/0.000)

Expressing Jitter : Eye diagram

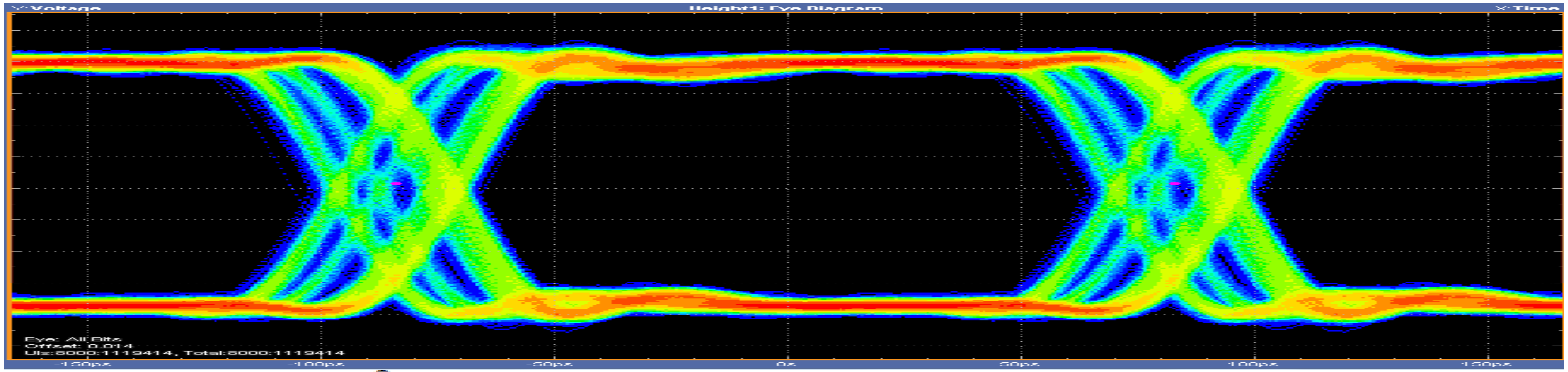


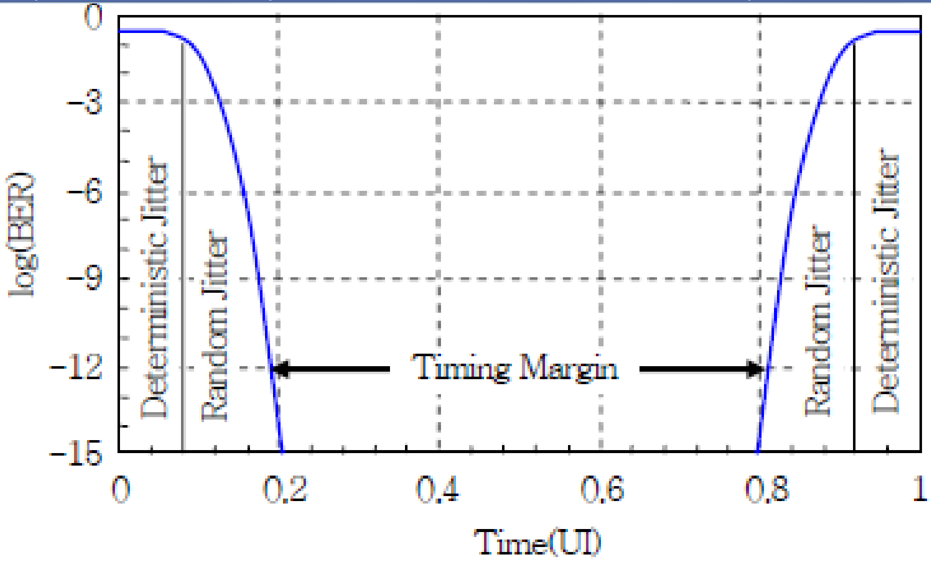






Expressing Jitter : Bathtub curve



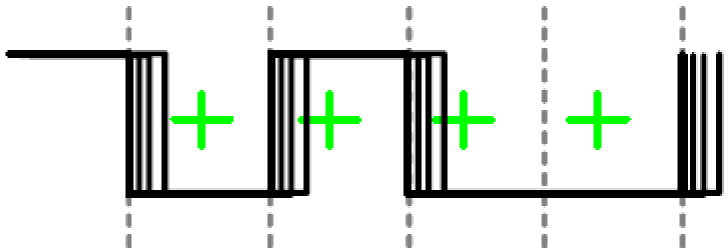


You can easily see Total Jitter at specified BER level using Bathtub curve

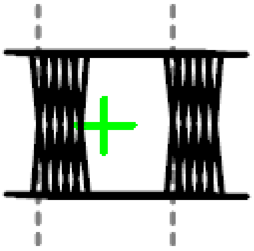
Jitter and Eye-diagram

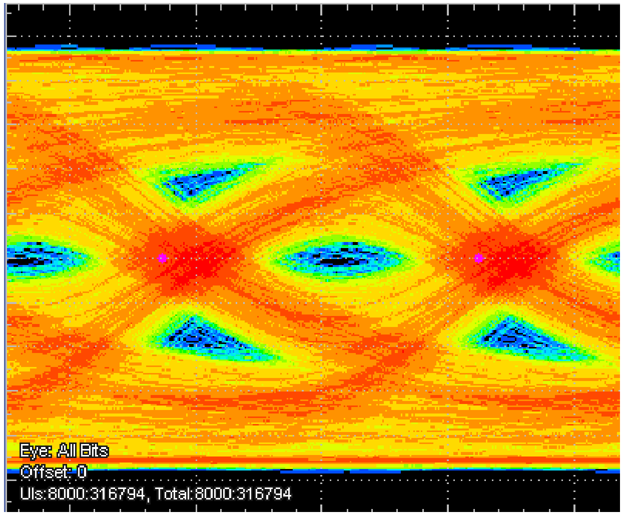
- Without Clock Recovery

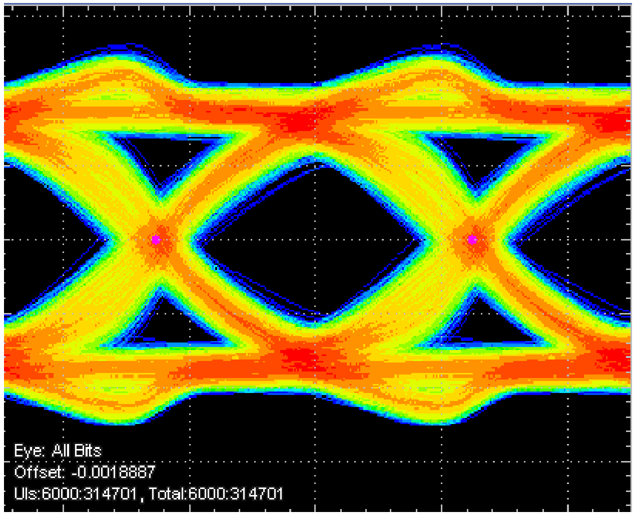
Bit Stream View



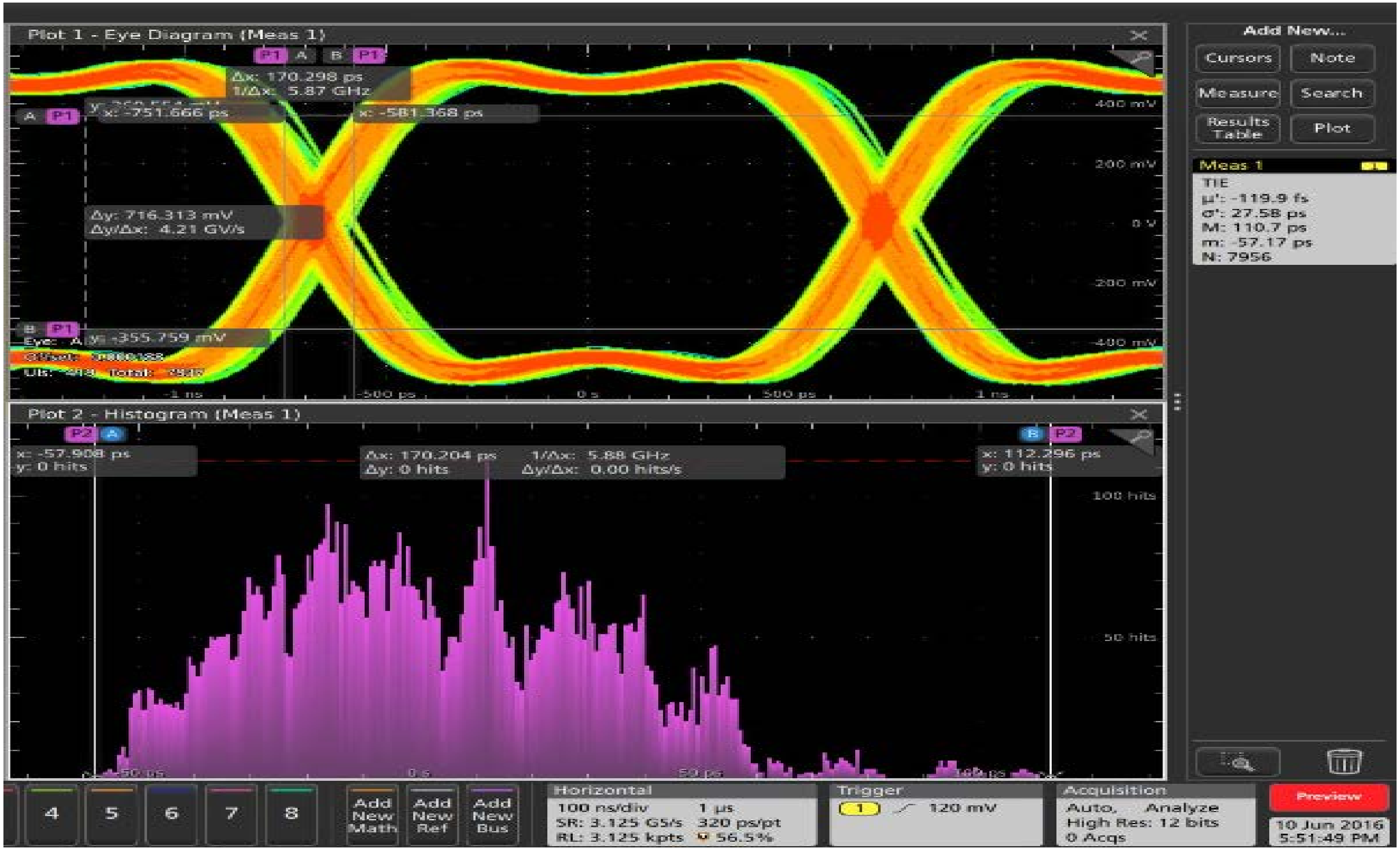
Eye Diagram View







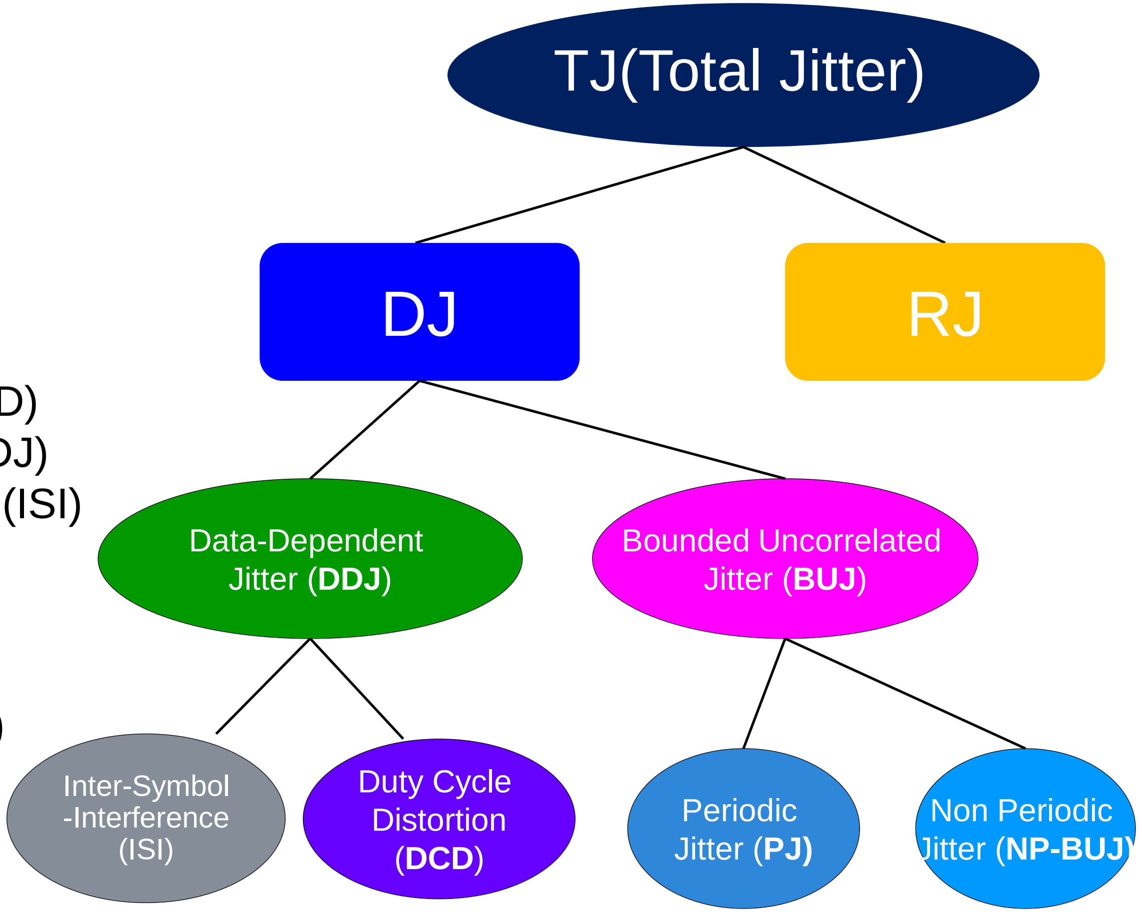
Jitter Measurement: Cursor and Histogram



Jitter Decomposition

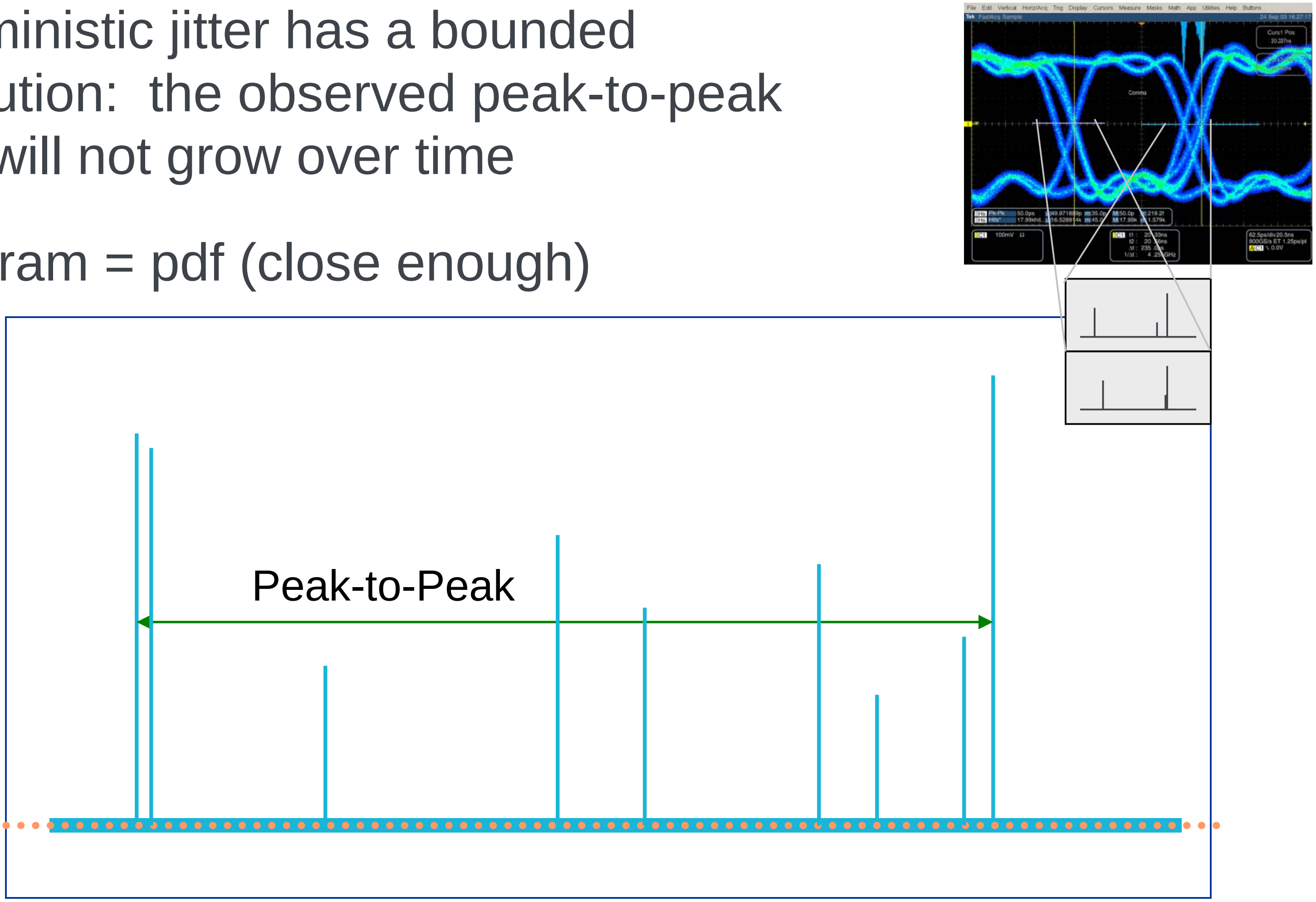
Common Terms:

- Random Jitter (RJ)
- Deterministic Jitter (DJ)
  - Periodic Jitter (PJ)
  - Sinusoidal Jitter (SJ)
  - Duty Cycle Distortion (DCD)
  - Data-Dependent Jitter (DDJ)
  - Inter-Symbol Interference (ISI)
- Bit Error Rate (BER)
- Total Jitter (TJ or TJ@BER)
- Eye Width @BER



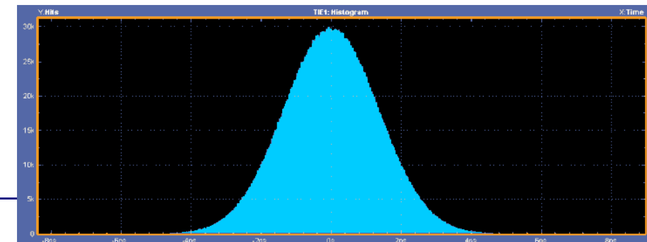
Deterministic Jitter (DJ)

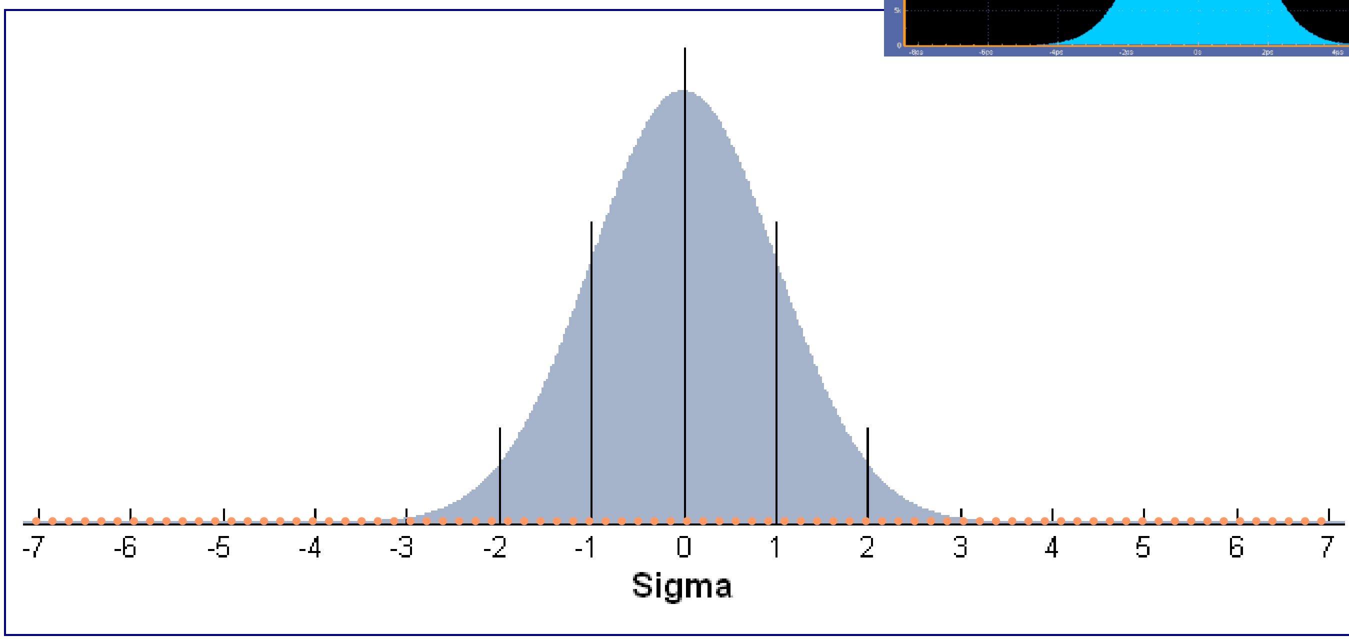
- Deterministic jitter has a bounded distribution: the observed peak-to-peak value will not grow over time
- Histogram = pdf (close enough)



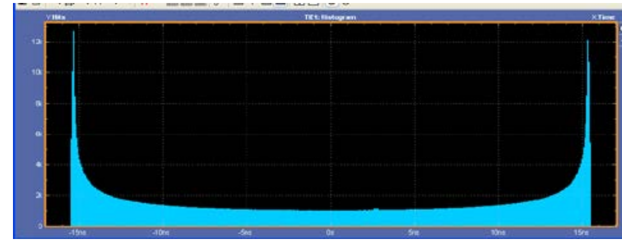
Random Jitter (RJ)

- Jitter of a random nature is assumed to have a Gaussian distribution (Central Limit Theorem)
- Histogram (estimate) ↔ pdf (mathematical model)
- Peak-to-Peak = … unbounded!

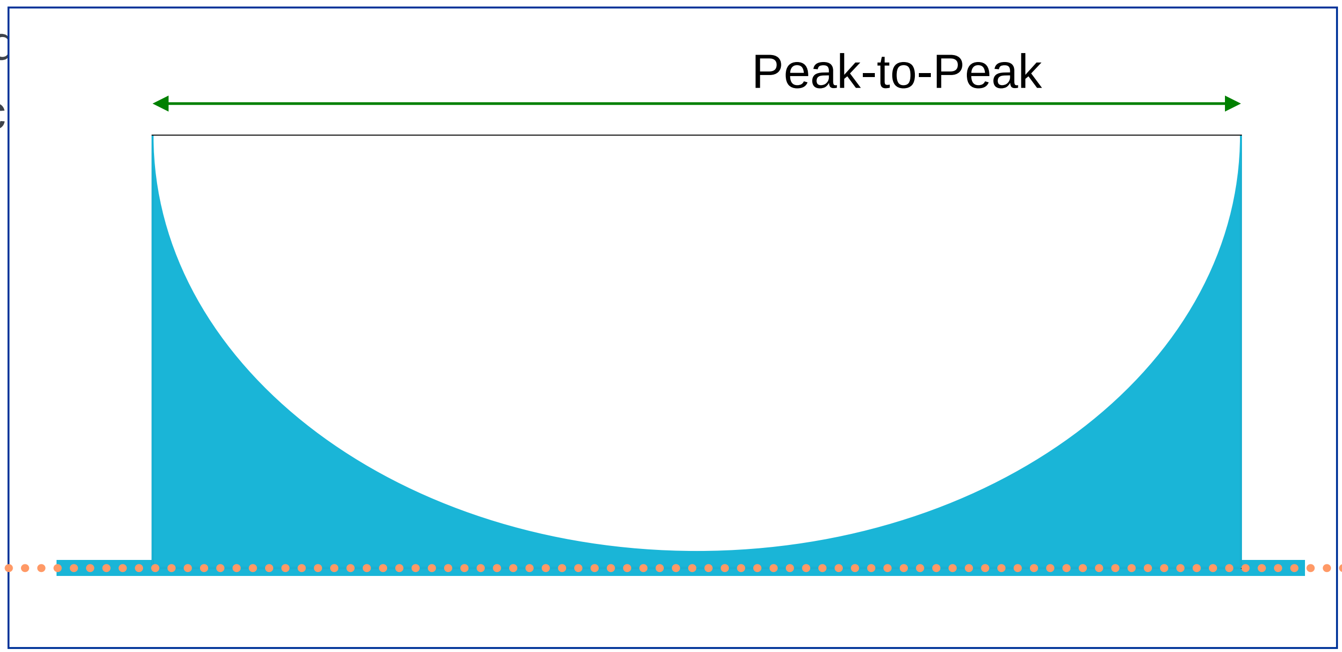




Periodic Jitter (PJ, SJ)

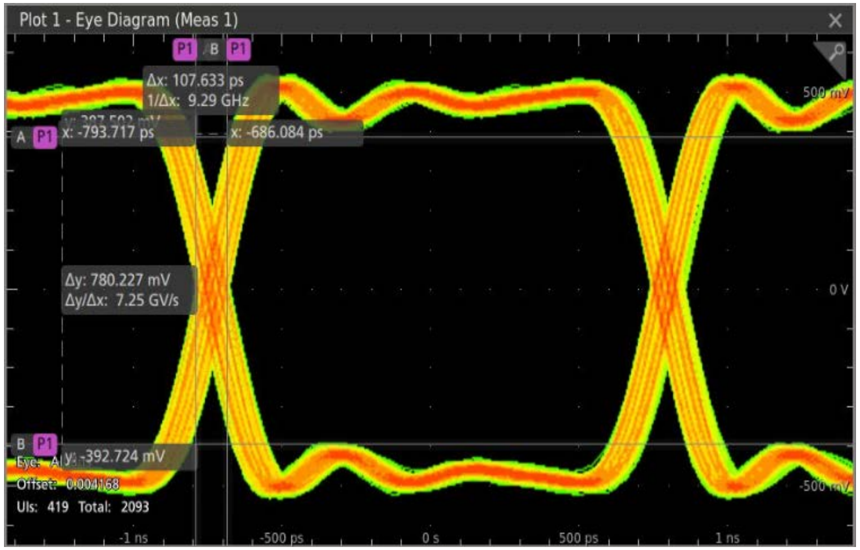


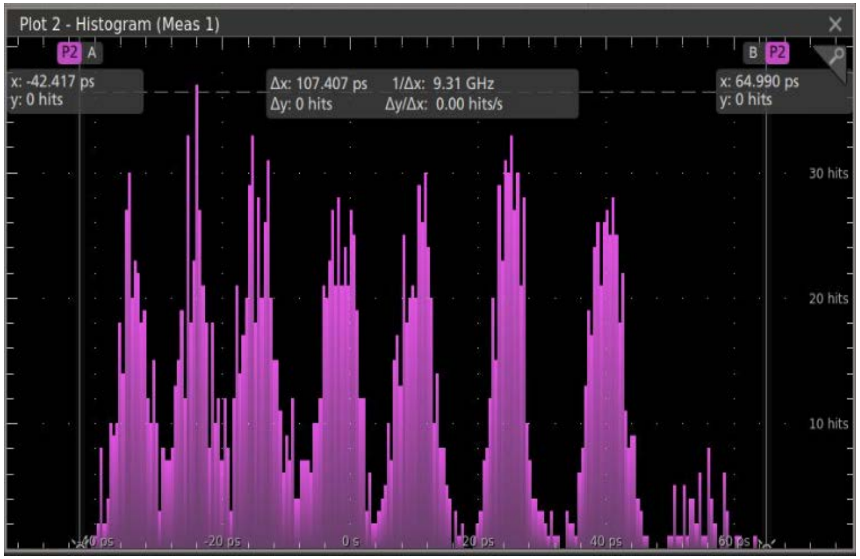
- TIE vs. time is a repetitive waveform
- Assumed to be uncorrelated with the data pattern (if any)
- Sinusoid
  Periodic



Data-Dependent Jitter

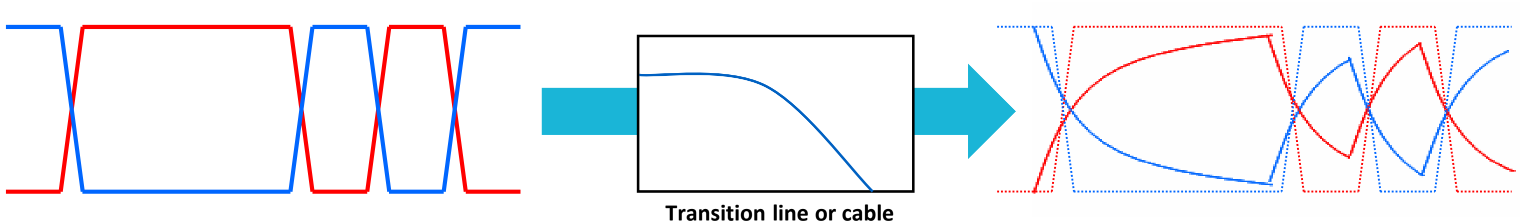
- DDJ or PDJ – used interchangeably
- ISI – usually considered to be the physical effect that causes DDJ
- Characterizes how the jitter on each transition is correlated with specific patterns of prior bits
  - Due to the step response of the system
  - Due to transmission line effects (e.g. reflections)





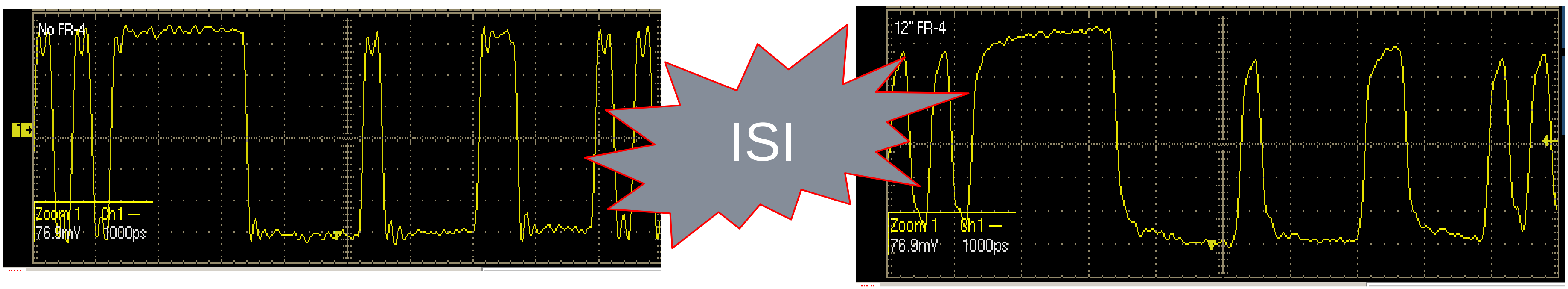
Inter-Symbol Interference (ISI)

- ISI or DDj or PDj – used interchangeably in the past, today we lean towards DDJ and we reserve ISI to describe the mechanism, not the measurement
- How a pattern effects subsequent bits
  - Due to transmission line effects, reflections, etc.



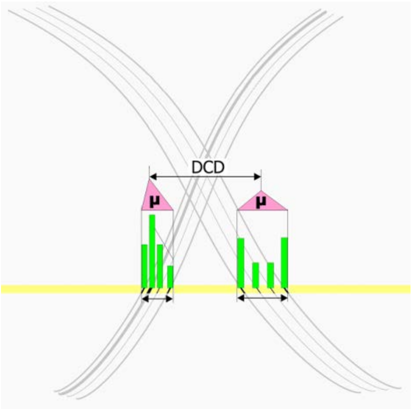
Transition line or cable

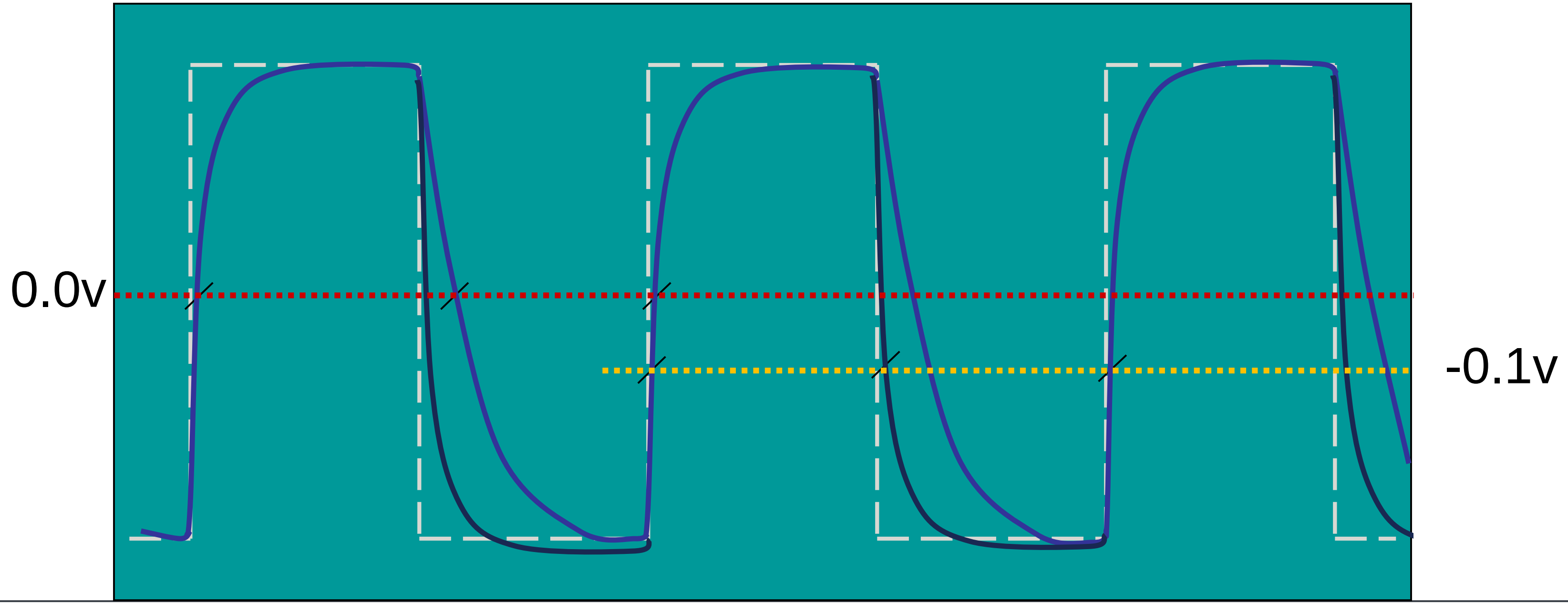
(LPF)



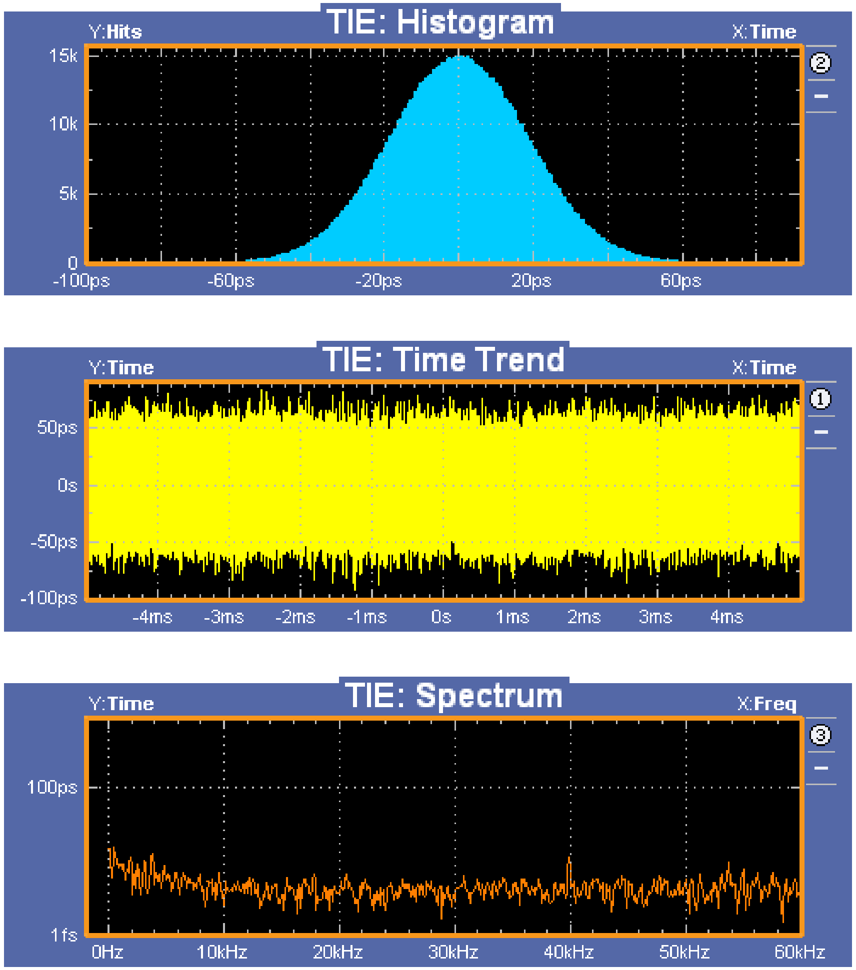
Duty Cycle Distortion (DCD)

- DCD is the difference between the mean TIE for rising edges and the mean TIE for falling edges
- Causes
  - Asymmetrical rise-time vs. fall-time
  - Non-optimal choice of decision threshold
- For a clock signal, the pdf consists of two impulses

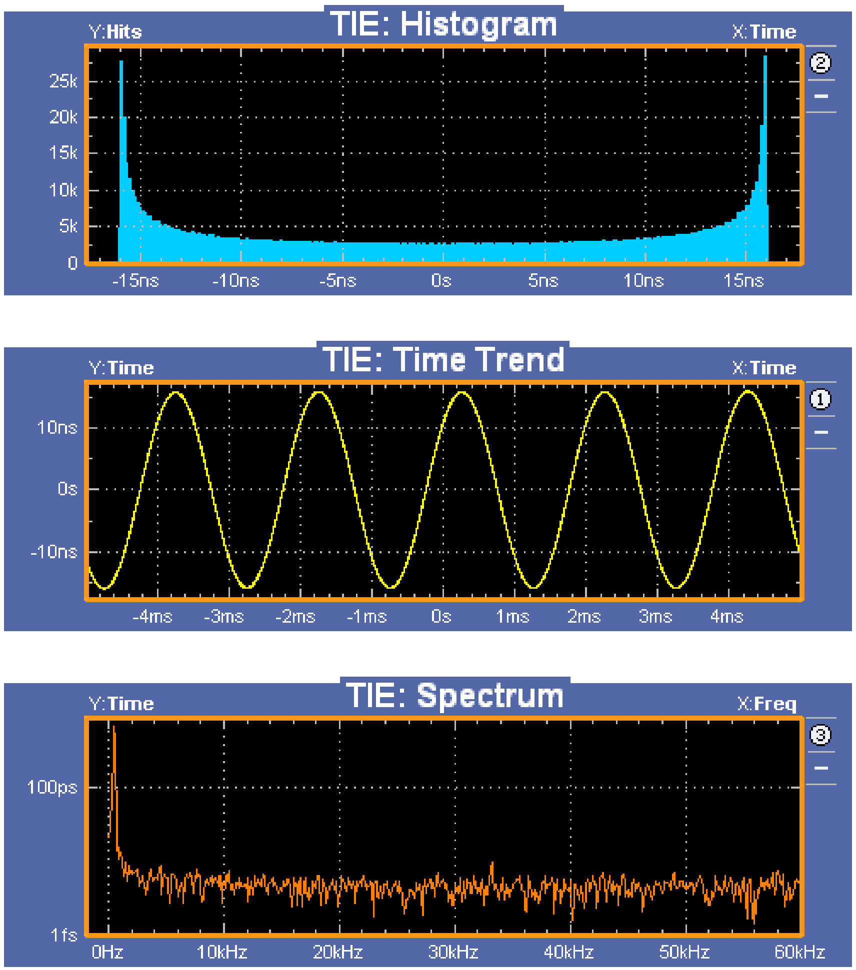




Jitter Visualization



Gaussian Random Jitter



Sinusoidal Jitter

Total Jitter & Bathtub

- **Total Jitter calculation from Dual-Dirac**

$$J_{pp}^{Total} = J_{pp}^{Random} + J_{pp}^{Deterministic} = 14 x \sigma + J_{pp}^{Deterministic}$$

- Convert RMS to Peak-to-Peak for Specific BERs

- 10^{-12} BER is the goal and thus a factor of 14 is used

- **Total Jitter calculation from spectrum method**

- Convolution of Dj and Rj Histogram

$$H^{Tj} = H^{Dj} \otimes H^{Rj}$$

Where: H^{Tj} is the recovered histogram of total jitter.

H^{Dj} is the histogram of Dj and is computed from the time record of Dj after the RjDj separation.

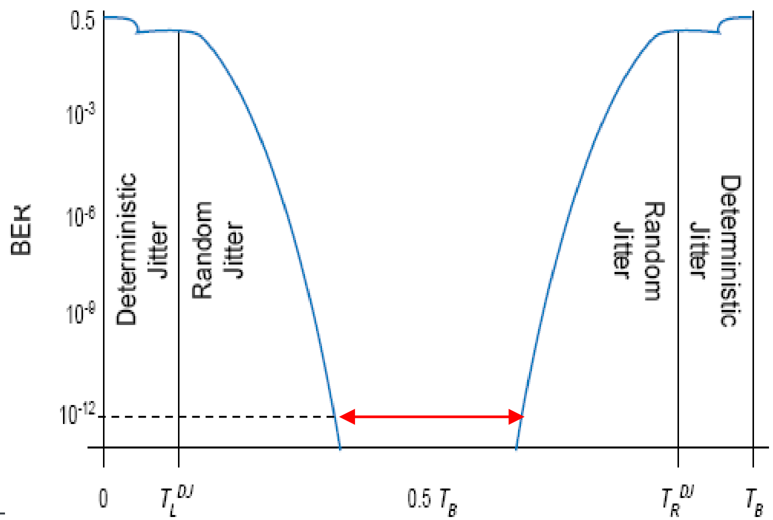
H^{Rj} is the histogram of Rj and is synthesized based on its Gaussian model after the RjDj separation.

- **The Bathtub Curve displays BER vs. sampling point in time**

-The tops of the curves are primarily due to deterministic jitter

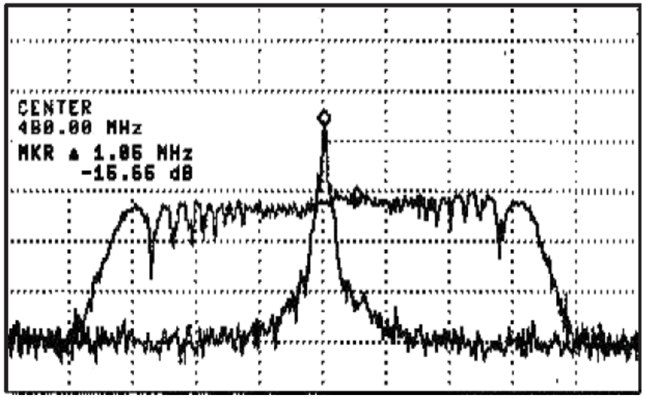
- Random jitter dominates the curve "tails" as they approach a BER

BER	Multiplier
10^{-4}	7.438
10^{-6}	9.507
10^{-7}	10.399
10^{-9}	11.996
10^{-11}	13.412
10^{-12}	14.069
10^{-13}	14.698
10^{-15}	15.883

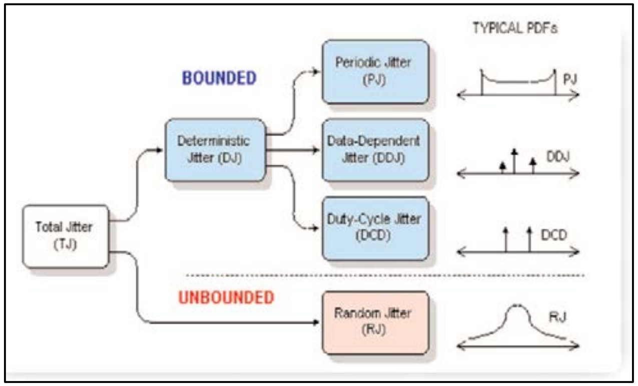


What Jitter are We Interested in?

- **A stand-alone oscillator Clock**
  - Hopping
  - SSC(Spread Spectrum Clocking) in a PC
  - Period Jitter is appropriate.



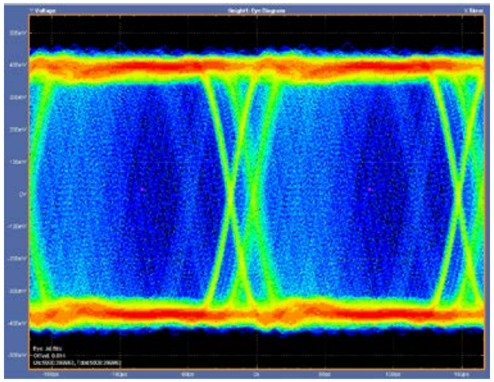
- **A transmitter for a Serial Data Stream**
  - ISI is the key problem
  - PJ(Periodic Jitter) , RJ(Random Jitter)
  - TIE is appropriate
  - Relative to the PLL Recovered Clock(CDR)



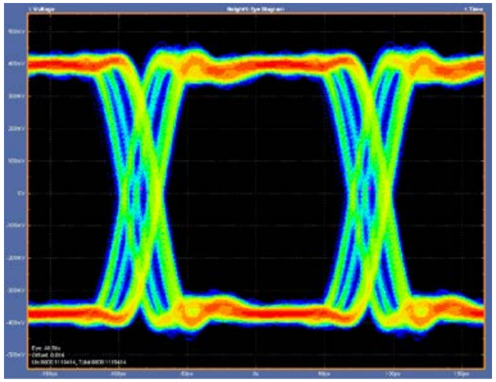
Importance of Clock Recovery

- Configuring the correct PLL settings is key to correct measurements
- Most standards have a reference/defined CR setup
  - For example, USB 3.0 uses a Type II with JTF of 4.9Mhz

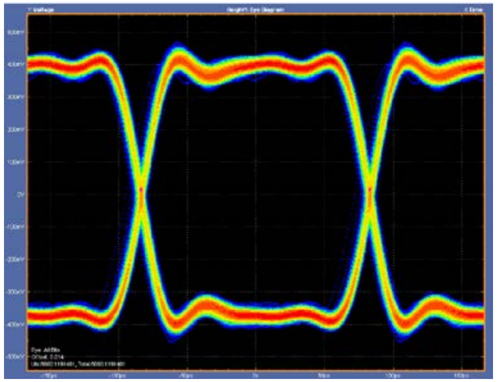
PLL Loop Bandwidth curve



f_{3dB} = 30 kHz

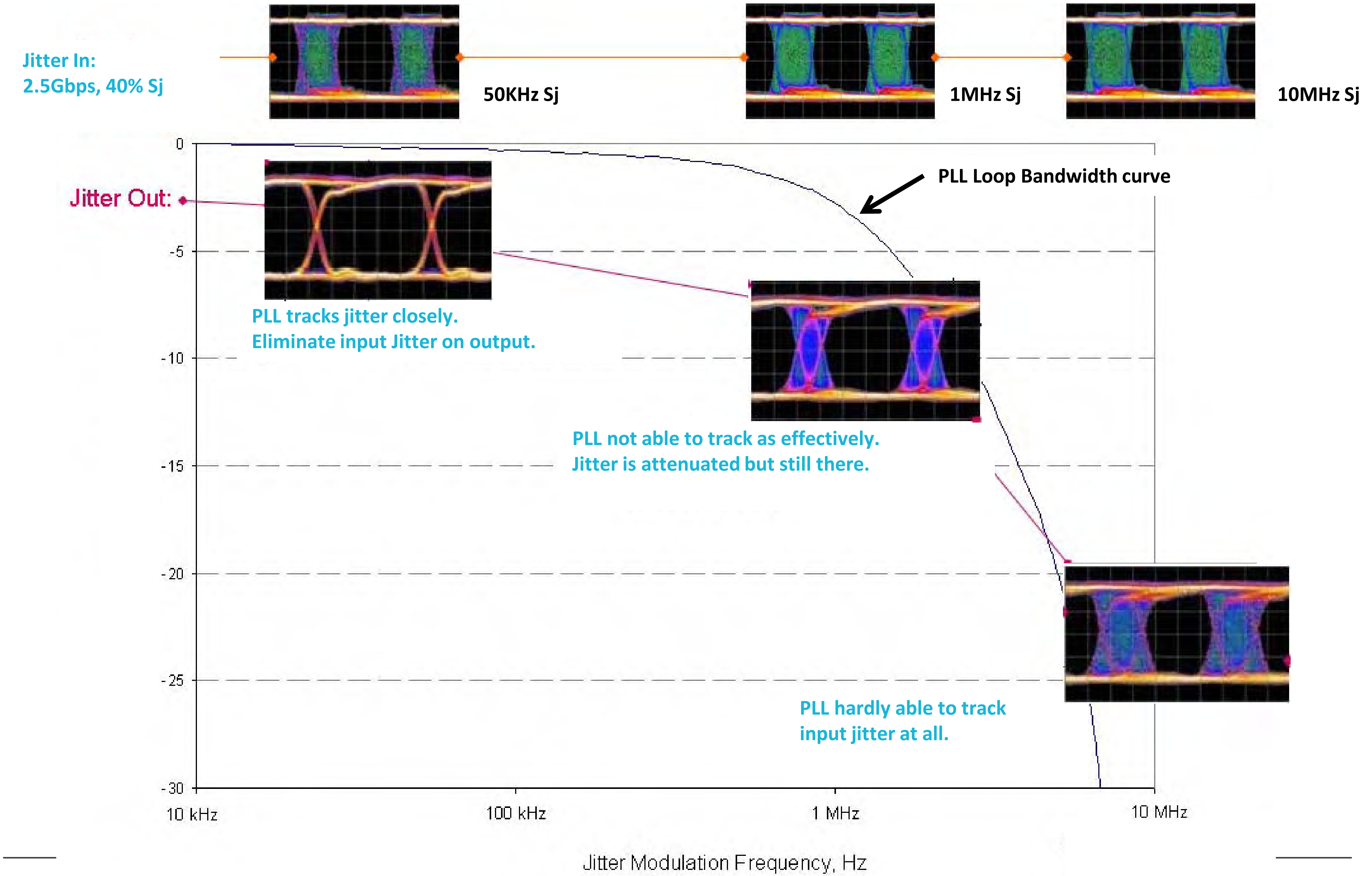


f_{3dB} = 300 kHz



f_{3dB} = 3 MHz

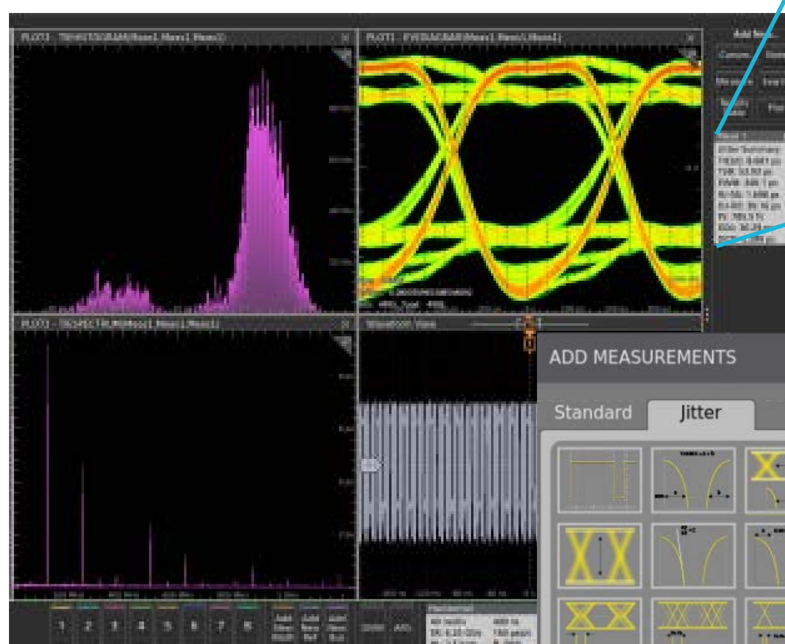
Jitter & Eye depending on Loop Bandwidth

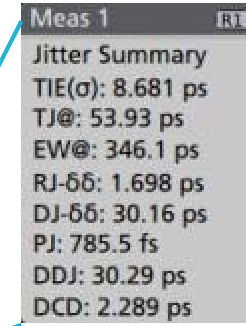


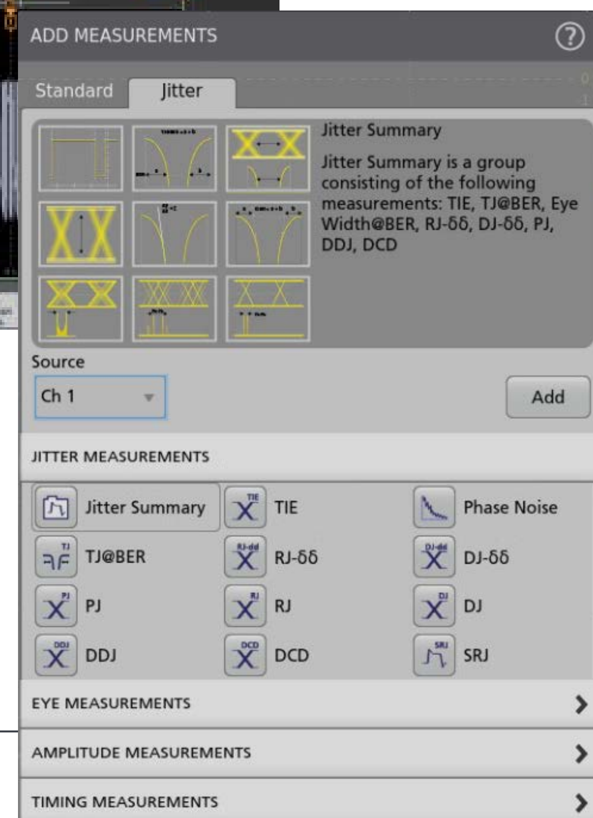
Jitter and Eye Analysis

OPTIONAL SOFTWARE PACKAGE

- DPOJET measurements are integrated into the scope application, providing faster and more intuitive operation
- Jitter measurements are accessed in the same simple manner as all other base measurements
- **New Jitter Summary** creates the following views
    - **Bathtub plot**
    - **TIE Histogram**
    - **TIE Spectrum**
    - **Eye Diagram**
    - **Most common jitter measurements**



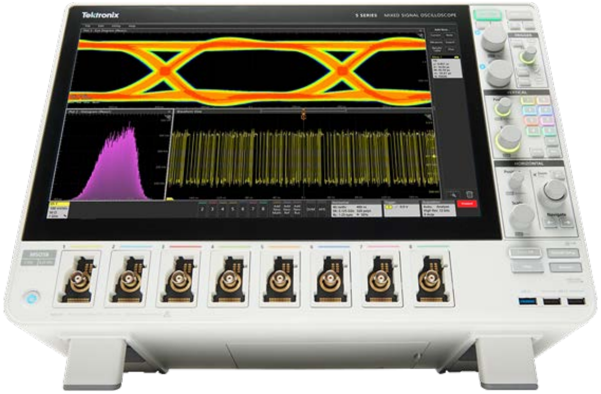




Demo:

Jitter and Eye Analysis

- DPOJET
- CDR



Thank you