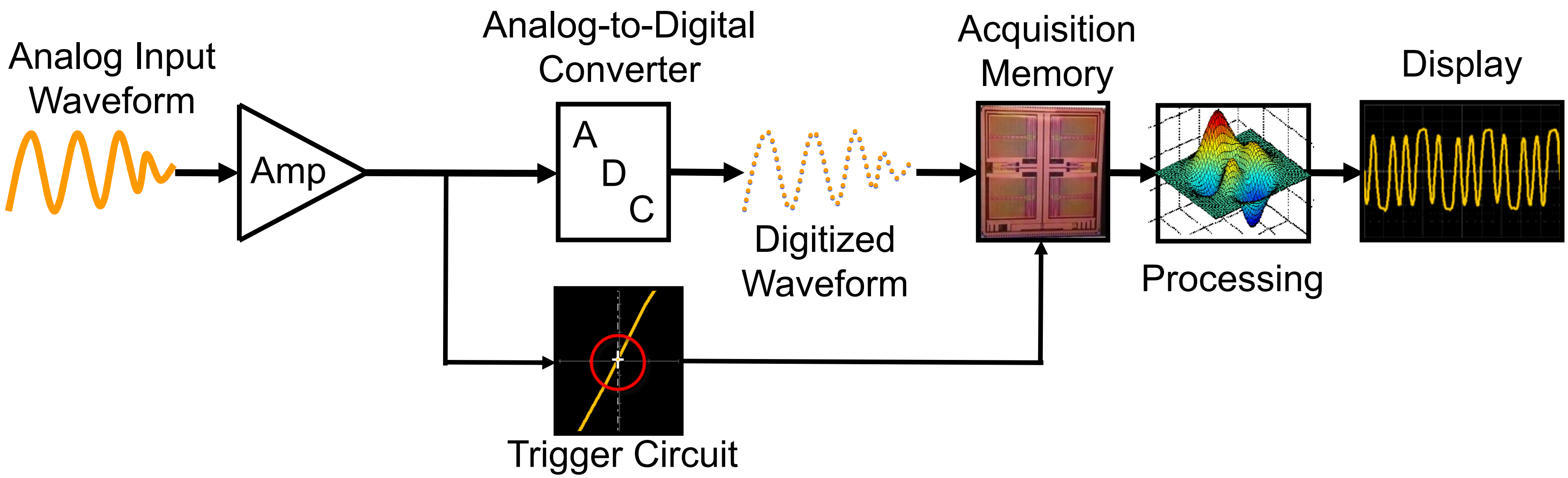
TeledyneLecroy示波器技术交流

Denny Li
Denny.li@teledynelecroy.com

Agenda

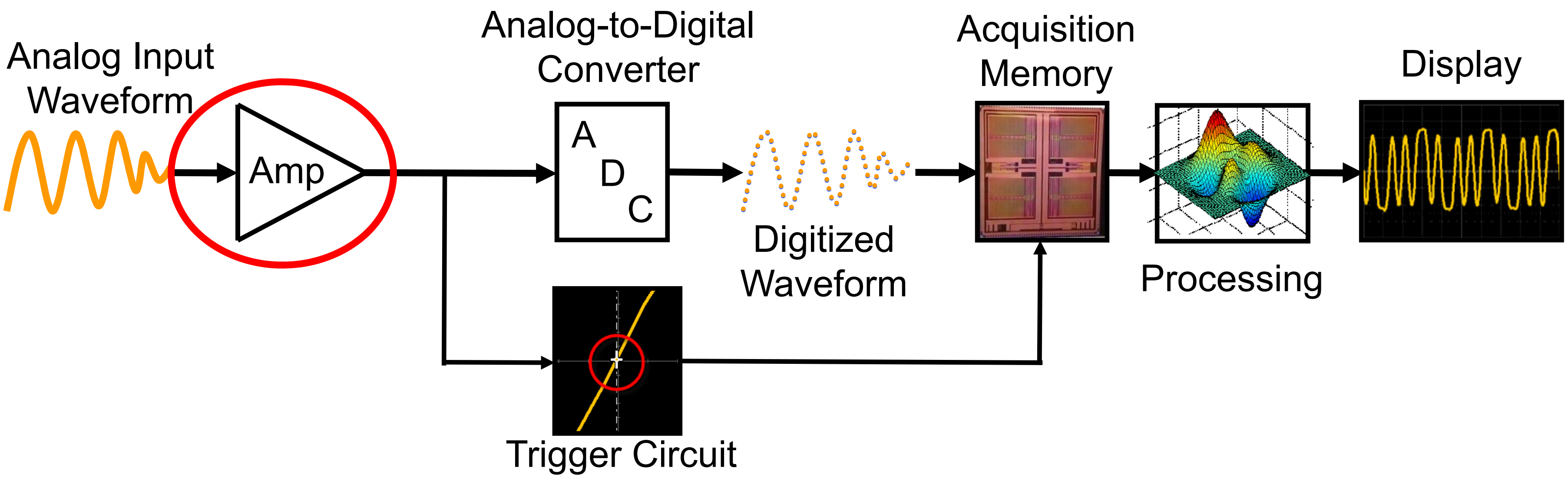
- **示波器基础介绍**

示波器框架图



- Amplifiers and attenuators scale the input signals amplitude to match the input range of the Analog to Digital Converter (ADC)
- The ADC samples the analog signal and converts the voltage into a digital number

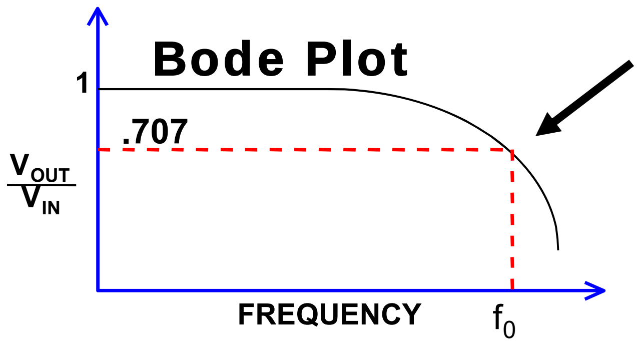
Analog Bandwidth



- Analog bandwidth is affected by the front end amplifier and other input analog circuits
- Digital bandwidth is affected by the sampling rate and the length of the acquisition memory

示波器模拟带宽

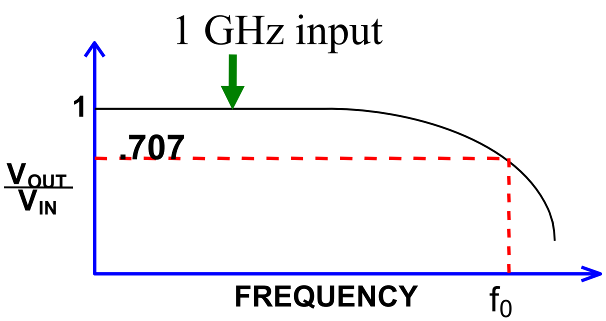
All oscilloscopes are specified with an analog bandwidth.



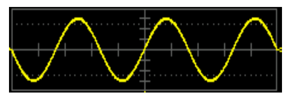
Analog bandwidth is the frequency at which the ratio of the amplitude displayed on the scope to the input amplitude is -3dB or .707

Scope Analog Bandwidth

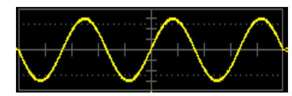
Example 1: A 3 GHz oscilloscope measures a **1 GHz** sine wave.



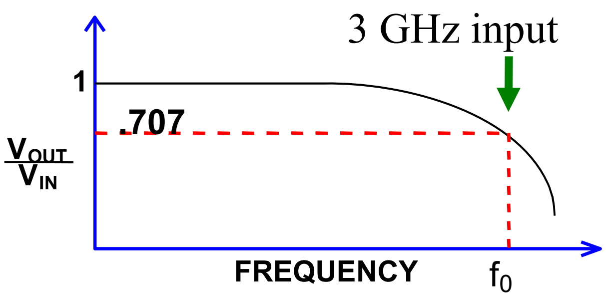
1 GHz, 1 V sinewave is input into oscilloscope



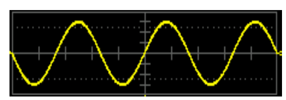
1 GHz, **1 V** sinewave is measured by oscilloscope



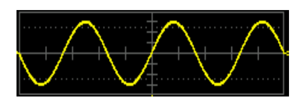
Example 2: A 3 GHz oscilloscope measures a **3 GHz** sine wave.



3 GHz, 1 V sinewave is input into oscilloscope



3 GHz, **0.707 V** sinewave is measured by oscilloscope



Bandwidth Selection:

Power Spectral Density Example of 28 Gb/s SERDES

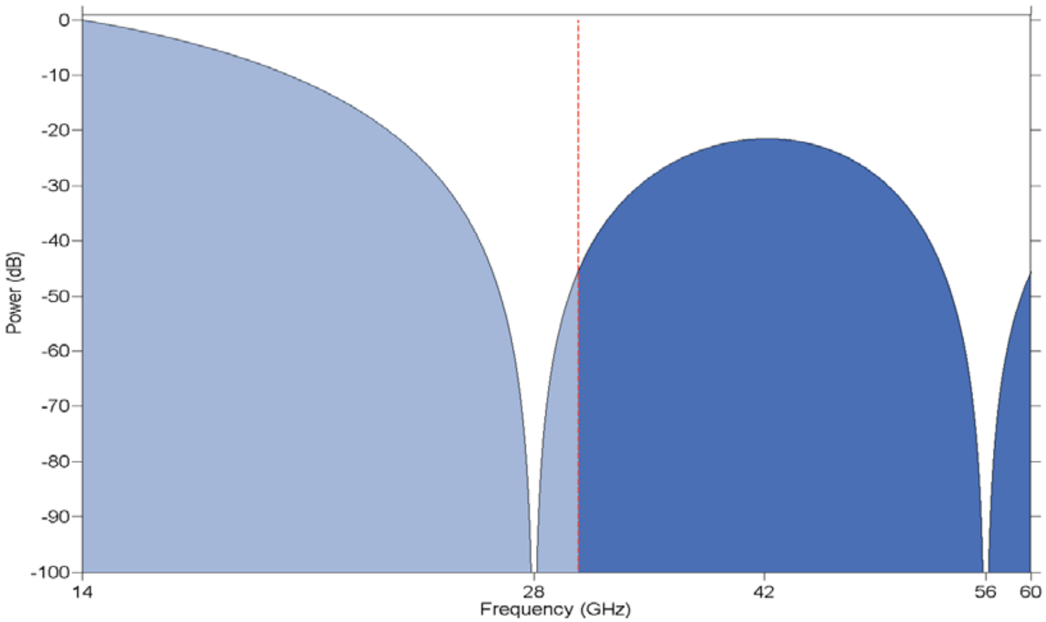
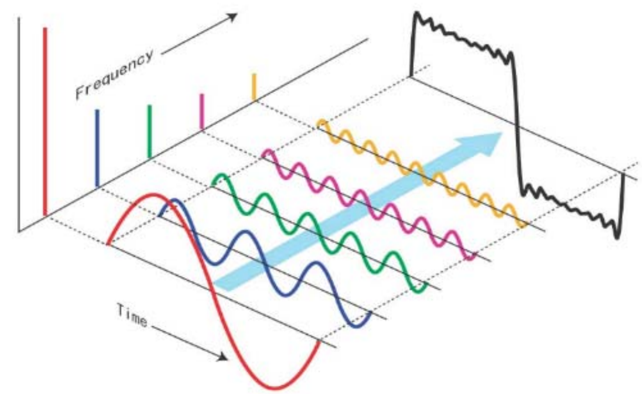


Illustration of harmonic content forming a bit pattern



The Power Spectral Density of a 28 Gb/s serial data waveform is plotted above, with Power (dB) on the Y-axis and Frequency (GHz) on the X-axis. For a 28 Gbps signal: the fundamental frequency is centered at 14 GHz, there is a null at 28 GHz, the third harmonic is centered at 42 GHz, and the next null is at 56 GHz. Therefore, an oscilloscope with at least 56 GHz bandwidth is needed in order to capture all of the power spectral density of the third harmonic of a 28 Gbps signal, and all of the PSD associated with the third harmonic will be captured by a LabMaster 10-60Zi 60 GHz oscilloscope. The darker blue area is the extra power spectral density provided by a 60 GHz oscilloscope compared to a 32 GHz oscilloscope.

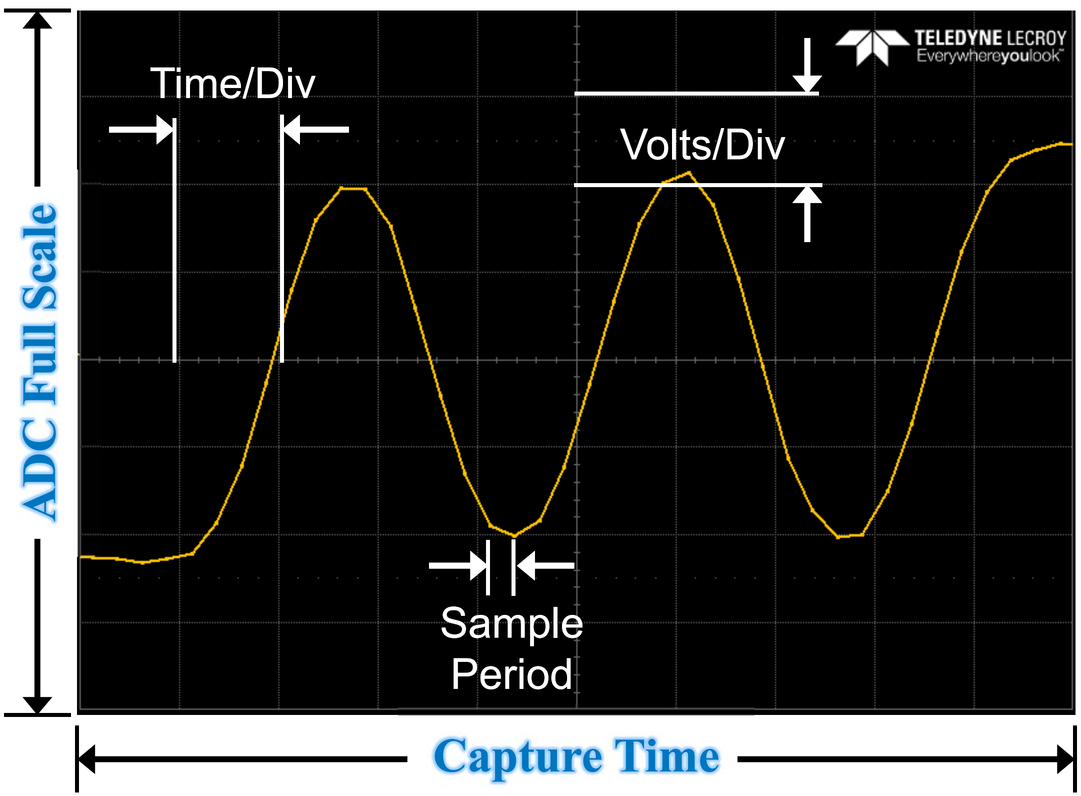
带宽选择

- 根据上升时间，计算信号带宽，然后计算所需的示波器带宽

  信号带宽=0.4/$TR_{(20\text{-}80)}$或0.5/$TR_{(10\text{-}90)}$

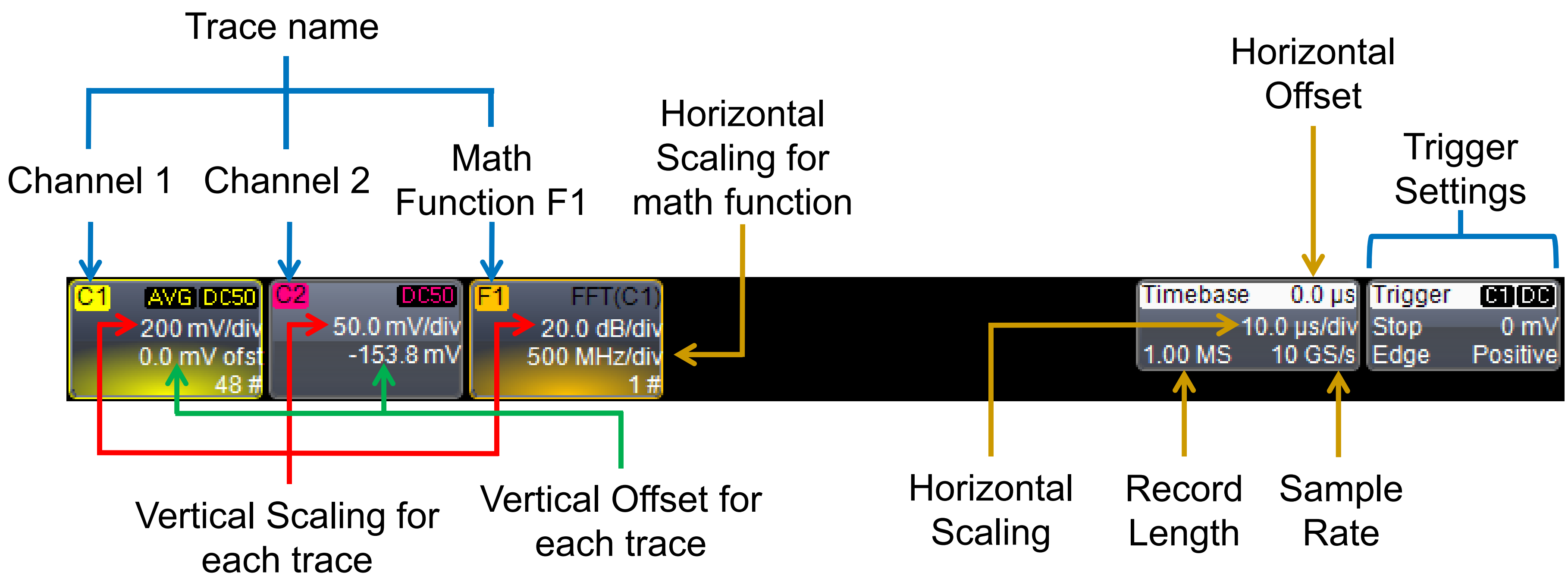
- 根据时钟信号频率，一般要求3-5倍的信号频率
- 根据串行数据速率，一般要求2.5倍的数据速率

Basic DSO Screen Layout



- **Vertical Range** = 8 x [Volts/Div] = 256 binary codes for 8-bit ADC
- **Capture Time** = 10 x [Time/Div]
- **Sample Rate** = 1 / Sample Period = Record Length / Capture Time
- **Record Length** = Sample Rate x Capture Time
- **Digital Bandwidth (Nyquist frequency)** = Sample Rate / 2
- **Lowest Characterized Frequency** = 1 / Capture Time
- **Ratio of highest to lowest observable frequency** = Record Length/2
- **Time Window =** Memory Depth / Sample Rate

Descriptor Boxes



Guidelines for Capturing Signals

Rule #1

Minimize Quantization Error

Rule #2

Capture at least one period of the slowest event that is of interest

Rule #3

Set the sample rate appropriately, watch out for Aliasing

Rule #4

Use special acquisition modes and processing methods when appropriate

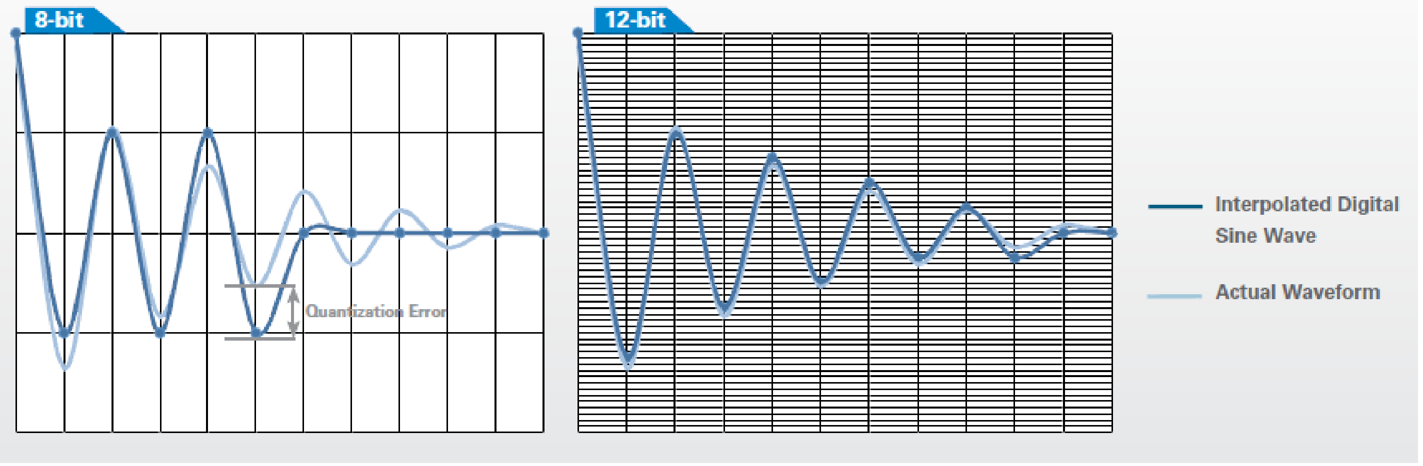
Rule 1: Minimize Quantization Error

- Available Quantization Levels in an ADC = $2^{\text{N bits of Resolution}}$

ADC Resolution	Number of Steps	Steps per Division	Dynamic Range
8	256	32	~48 dB
12	4096	512	~72 dB

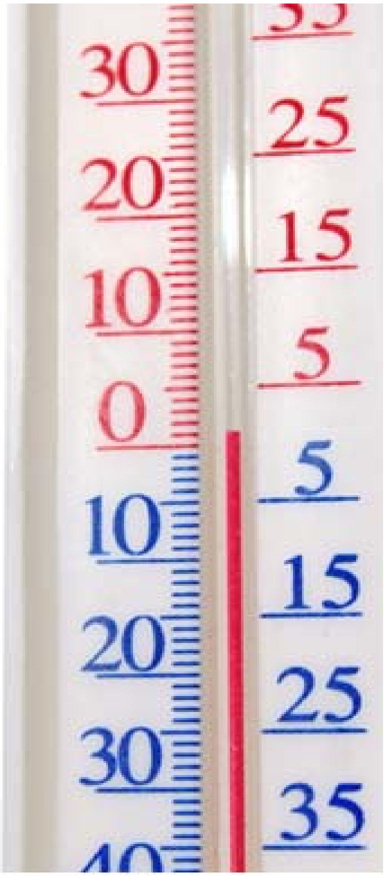
Quantization is mapping a large set of values to a smaller set of values

- Quantization levels – 16 times more for 12-bit scopes



量化等级的比喻

- 常用的温度计上的刻度可以很好得比喻量化等级的概念
- 右边的刻度是每10°C一个等级，左边明显更精细一些，达到1°C一个等级
- 左边的刻度量化等级是右边的10倍，意味着能够进行更加精确的温度测量

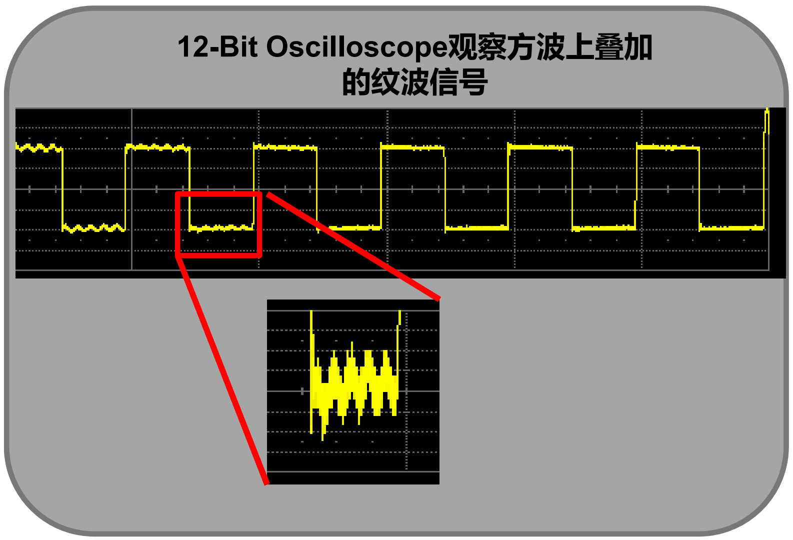


右边:
温度介于 -5° 和 +5°, 接近 0°

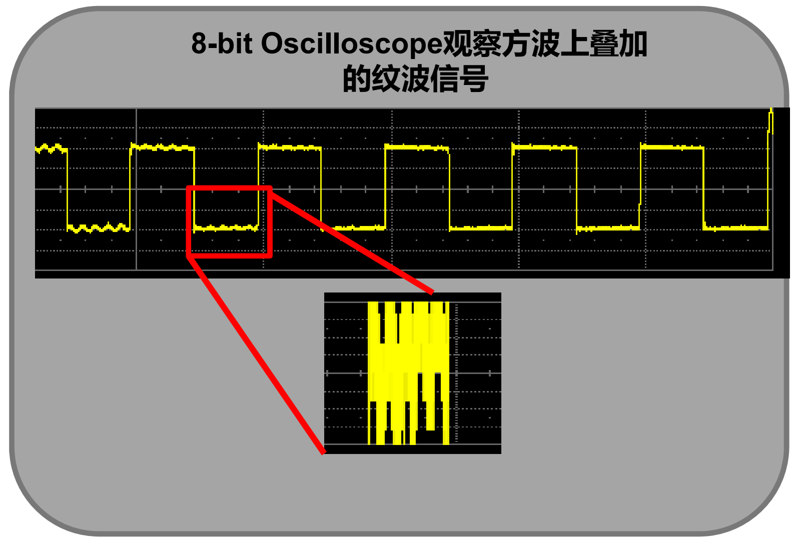
左边:
温度精确测量是+1 °

12bit VS 8bit–看到更多的信号细节

- 更高的垂直分辨率让波形细节一览无余，8bit示波器的信号细节则淹没在量化噪声当中



可以观察并测量纹波参数(频率，rms等)



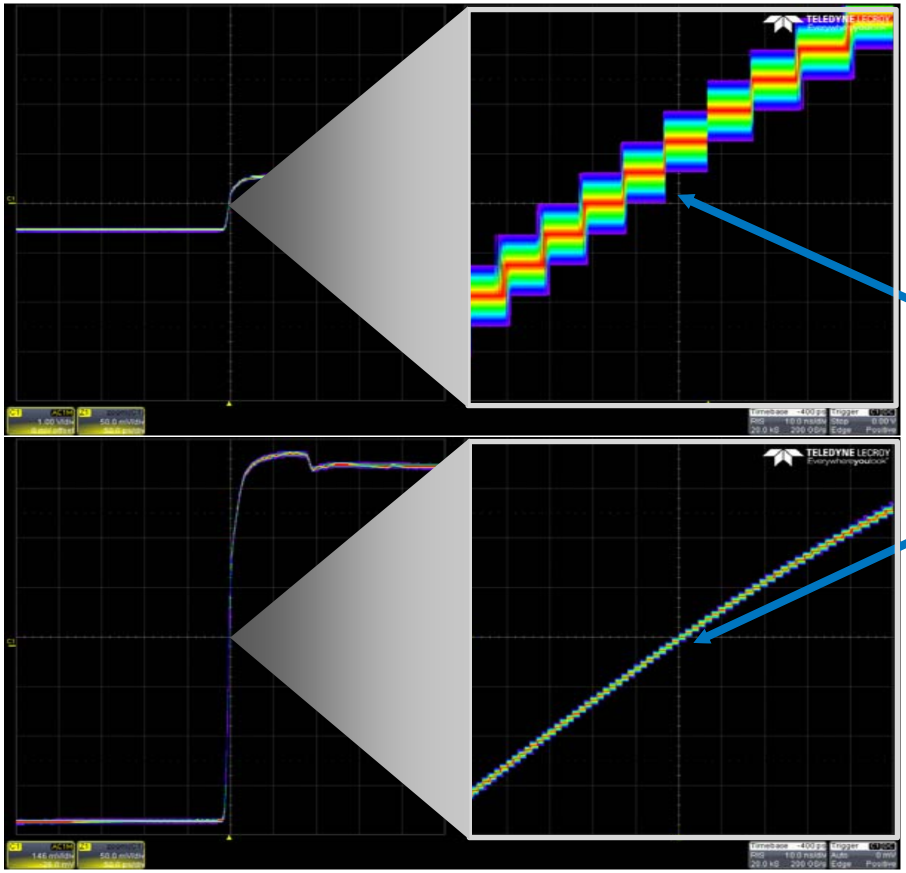
能看到纹波吗？

HDO Family of Oscilloscopes

	HDO4000A	HDO6000A	HDO8000A	HDO9000
HD Technology	HD4096 12 bits	HD4096 12 bits	HD4096 12 bits	HD1024 10 bits
Bandwidth	200 MHz – 1 GHz	350 MHz – 1 GHz	350 MHz – 1 GHz	1 GHz – 4 GHz
Input Channels	2, 4	4	8	4
Sample Rate	10 GS/s	10 GS/s	10 GS/s	40 GS/s
Analysis Capability	Basic	Advanced	Advanced	Exceptional

Quantization Error

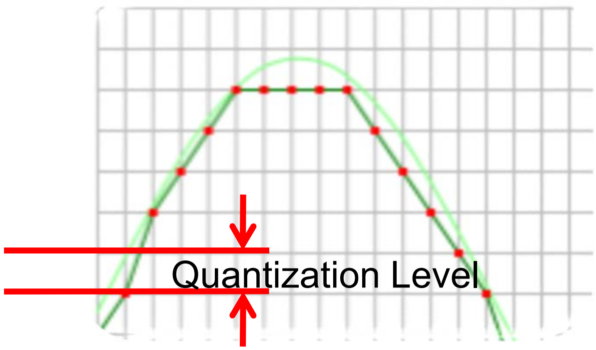
4x attenuation of signal produces 4x larger quantization steps = 2 bits less resolution!



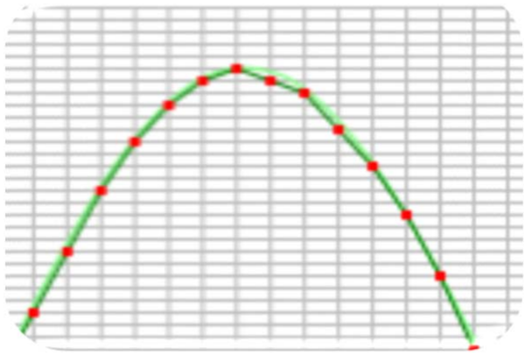
Zooms of rising edges show quantization levels

Quantization Error

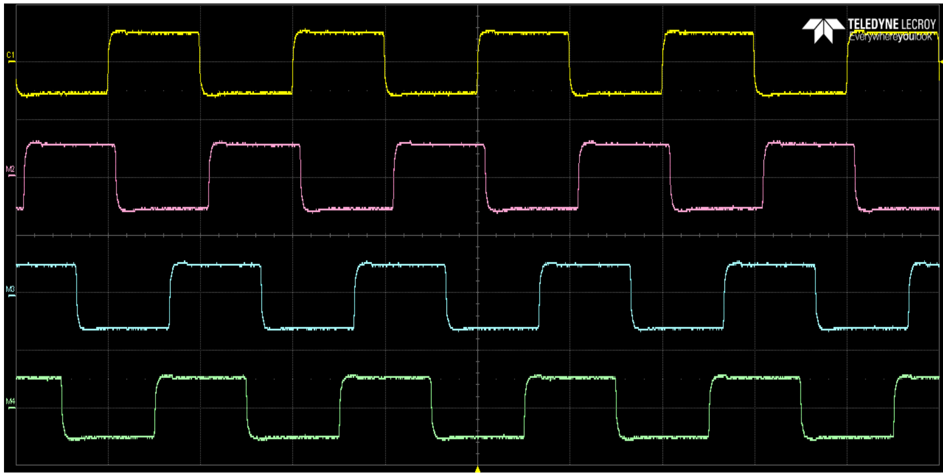
- An 8-bit ADC can represent 256 quantization levels
- A full-scale signal will utilize the full range of the ADC
- Scaling the signal to less than full scale increases the quantization step size and decreases accuracy
  - **Full Scale = 8-bit resolution**
  - **½ Scale = 7-bit resolution**
  - **¼ Scale = 6-bit resolution**
  - **Uncertainty = $V_{full\ scale} / 2^n$, where n = number of bits**
- Variable gain may be used to precisely match signal size to the range of the ADC



Not Full-scale Signal

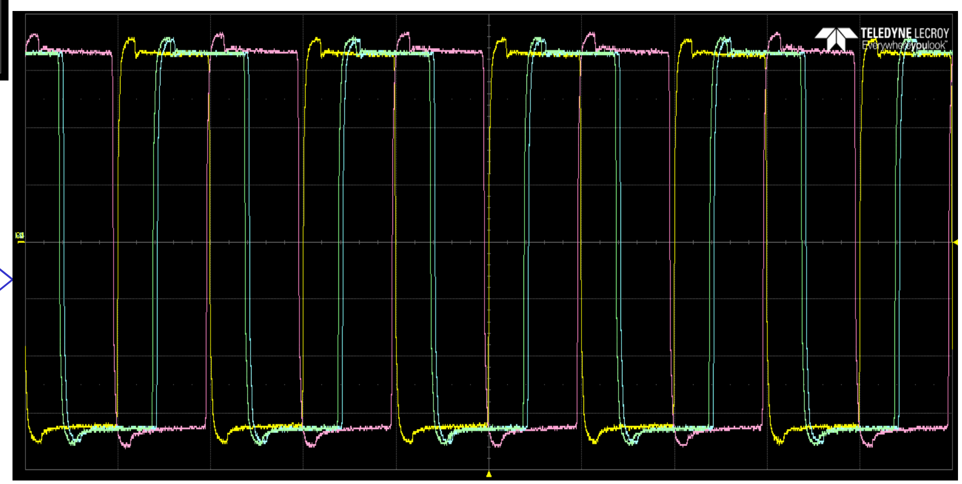

Full-scale Signal

Some scopes make you choose…

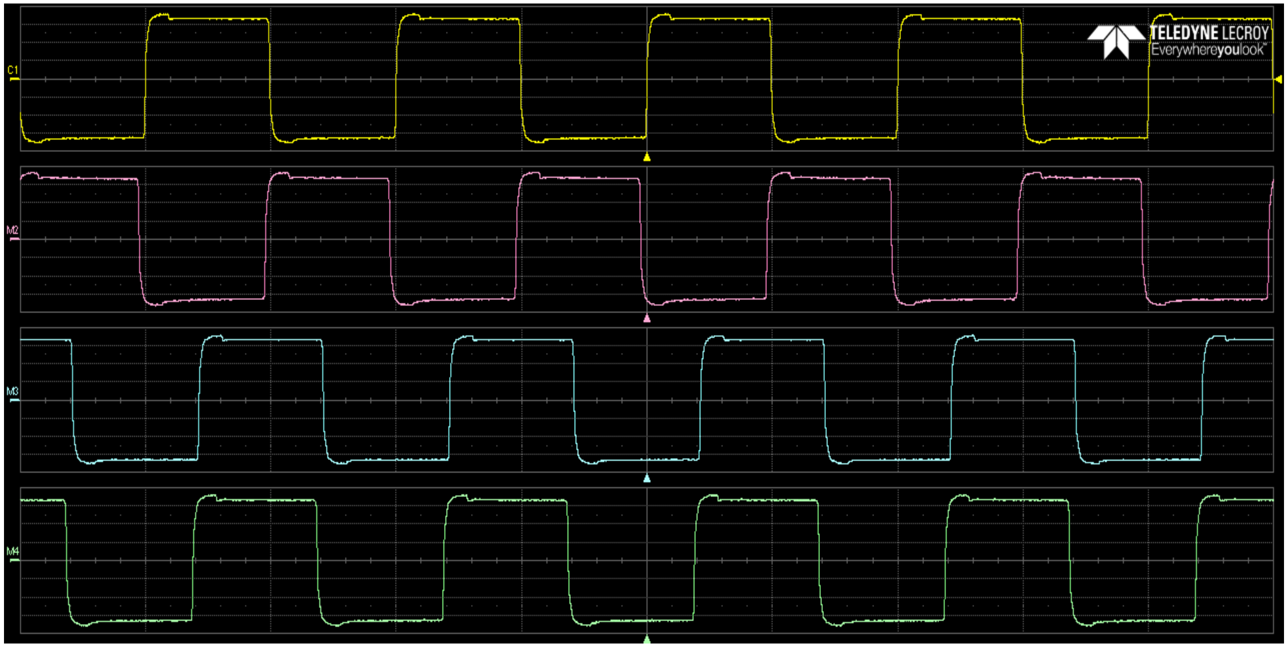


Shrinking each trace to ¼ scale reduces vertical resolution to 6 bits but allows all traces to be viewed

Scaling signals to full screen maintains full 8-bit vertical resolution but makes it impossible to view individual traces



Multi-Grid Eliminates Compromise

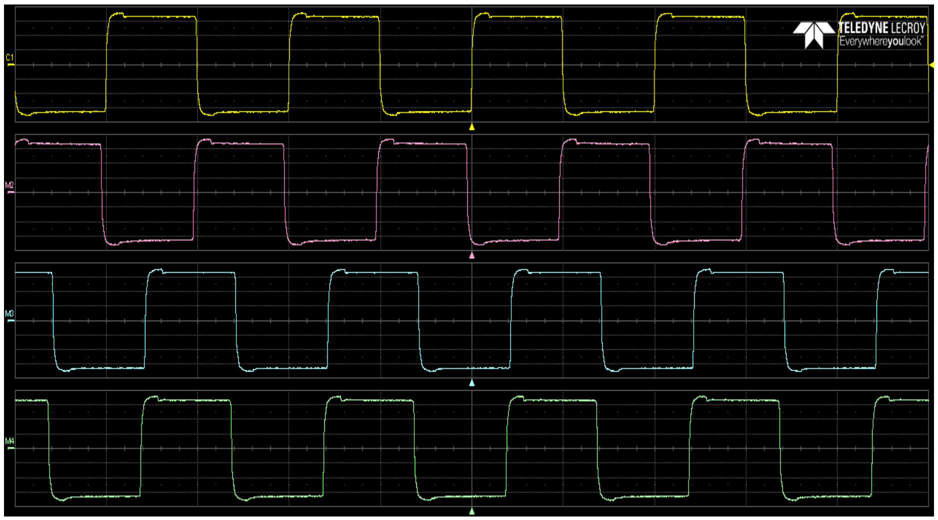


Multi-Grid display provides full 8-bit vertical resolution for each input channel

- Multi-Grid display enables independent, full-scale view of each trace
- Eliminates compromise between vertical resolution and viewability
- User may select number and layout of grids
- Any number of traces may be placed in any grid

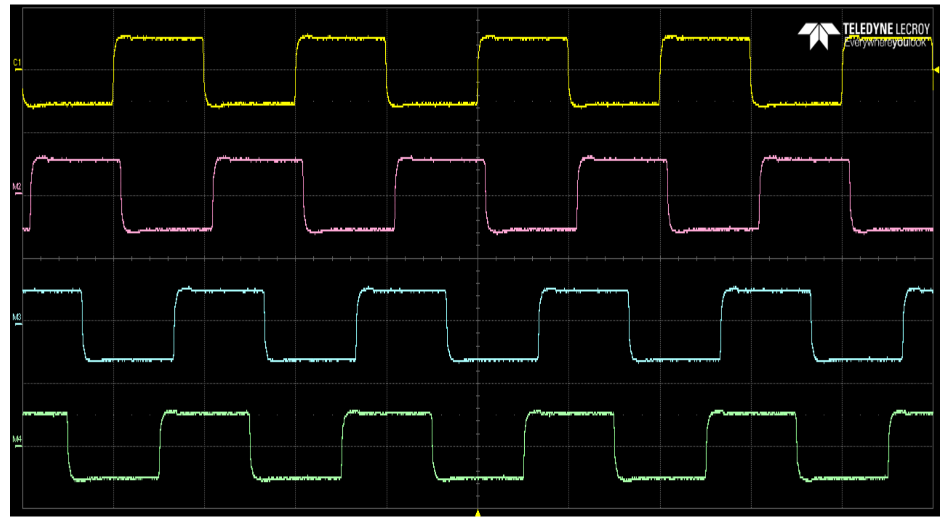
Multi-Grid Improves Amplitude Accuracy

4 Traces 4 Individual Grids



StdVer	P1:pkpk(C1)	P2:ampl(C1)	P3:max(C1)
value	1.141 V	1.0470 V	574 mV
mean	1.140037 V	1.047144 V	575.062 mV
min	1.134 V	1.0448 V	571 mV
max	1.148 V	1.0498 V	583 mV
sdev	1.954 mV	1.456 mV	1.393 mV
num	1.034e+3	1.034e+3	1.034e+3
status	✓	✓	✓

4 Traces Share Single Grid

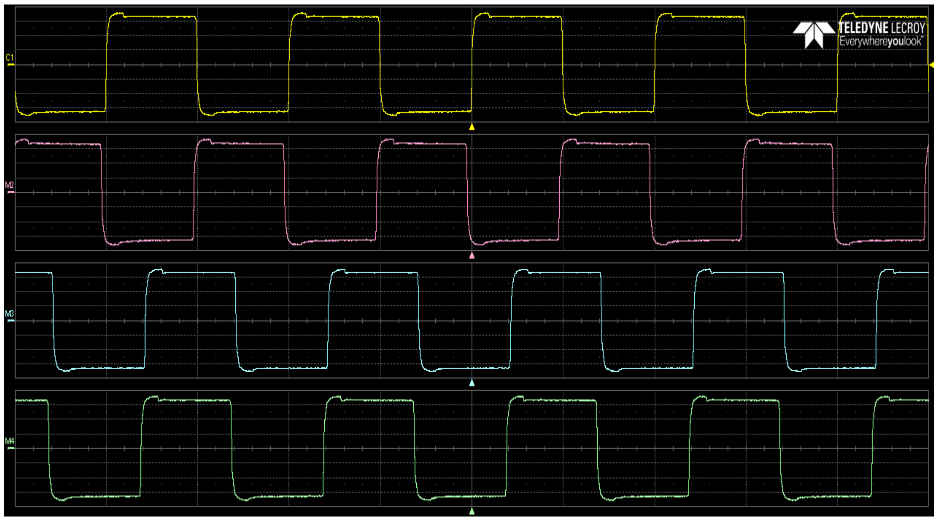


StdVer	P1:pkpk(C1)	P2:ampl(C1)	P3:max(C1)
value	1.17 V	1.063 V	567 mV
mean	1.163852 V	1.062397 V	564.139 mV
min	1.15 V	1.050 V	553 mV
max	1.19 V	1.063 V	579 mV
sdev	5.625 mV	1.061 mV	4.303 mV
num	1.070e+3	1.070e+3	1.070e+3
status	✓	✓	✓

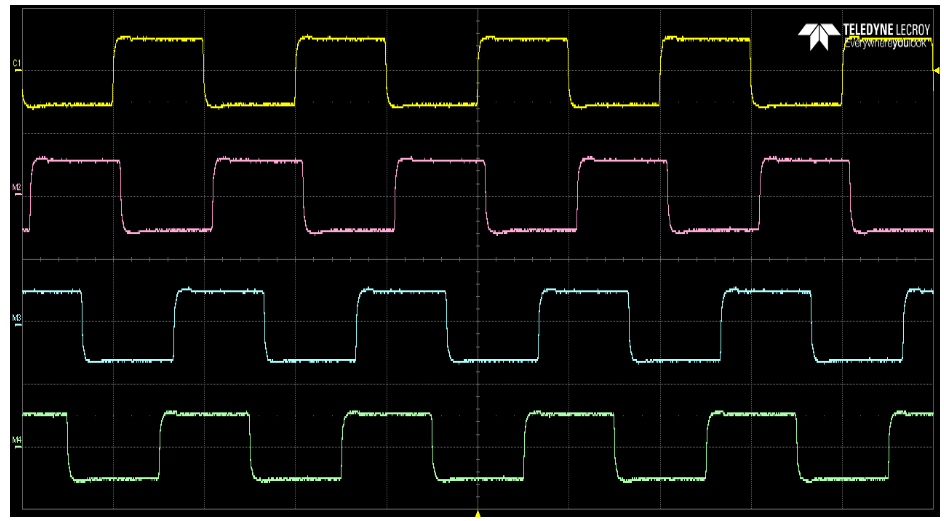
Reduced standard deviation indicates improved measurement accuracy

Multi-Grid Improves Timing Accuracy

4 Traces 4 Individual Grids



4 Traces Share Single Grid

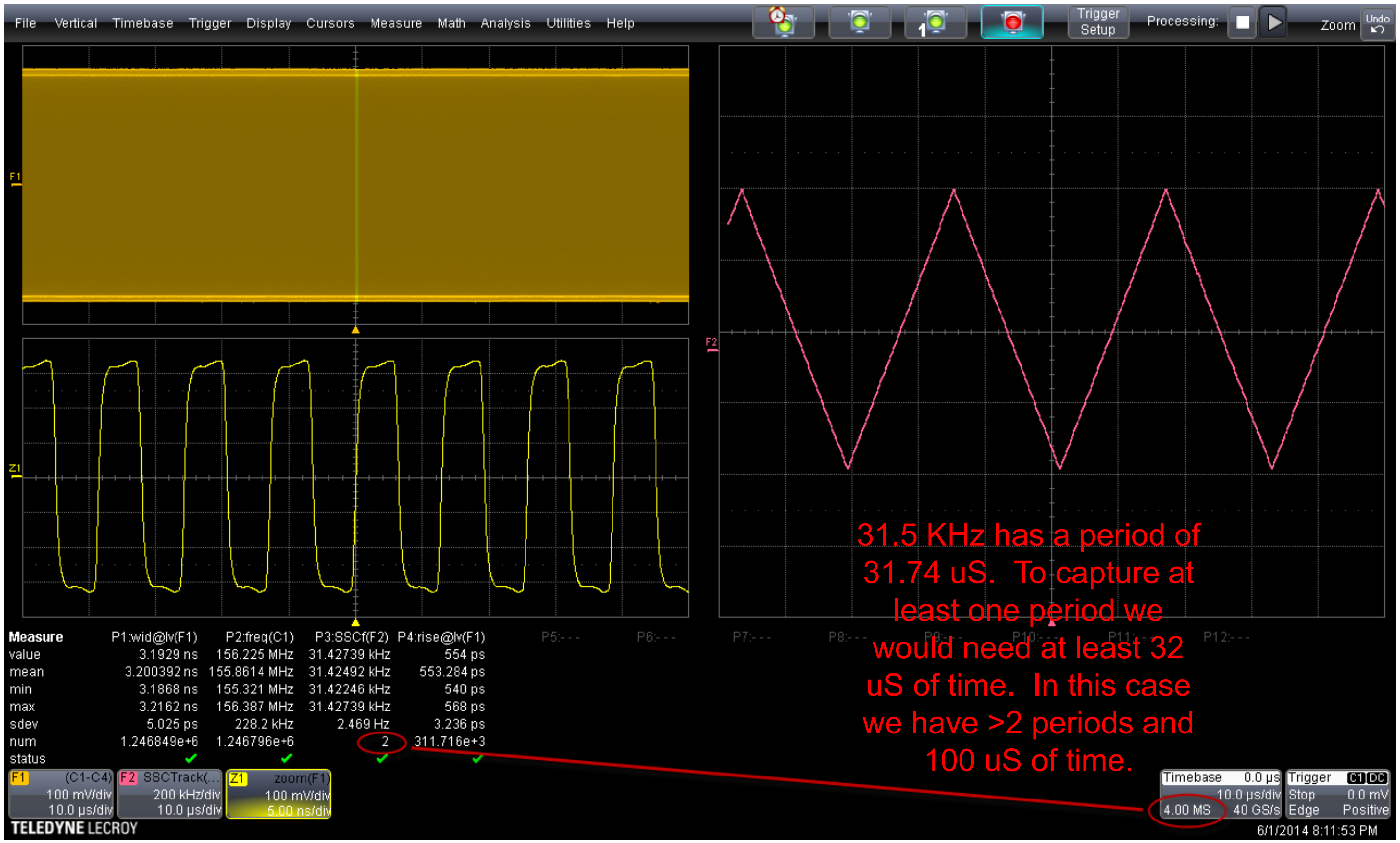


StdHor	P1:rise(C1)	P2:fall(C1)	P3:period(C1)
value	2.933 ns	3.028 ns	199.9697 ns
mean	2.98483 ns	3.02228 ns	200.00073 ns
min	2.854 ns	2.911 ns	199.9419 ns
max	3.105 ns	3.128 ns	200.0525 ns
sdev	37.48 ps	38.60 ps	22.54 ps
num	1.070e+3	856	856
status	✓	✓	✓

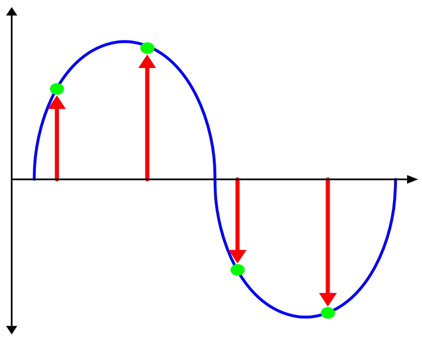
Reduced standard deviation indicates improved measurement accuracy

StdHor	P1:rise(C1)	P2:fall(C1)	P3:period(C1)
value	3.008 ns	3.113 ns	200.0211 ns
mean	3.0985 ns	3.2159 ns	200.00151 ns
min	2.722 ns	2.821 ns	199.8792 ns
max	3.500 ns	3.629 ns	200.0911 ns
sdev	128.4 ps	125.2 ps	30.32 ps
num	1.145e+3	916	916
status	✓	✓	⚠

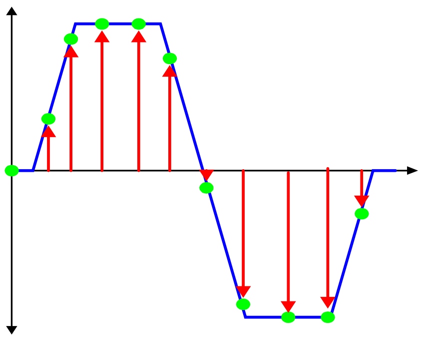
Rule 2: Capture at least one period of the signal of interest



Rule 3: Set the sample rate appropriately – watch out for Aliasing



Narrowband waveforms such as sine waves should be sampled at minimum 4 times the signal frequency

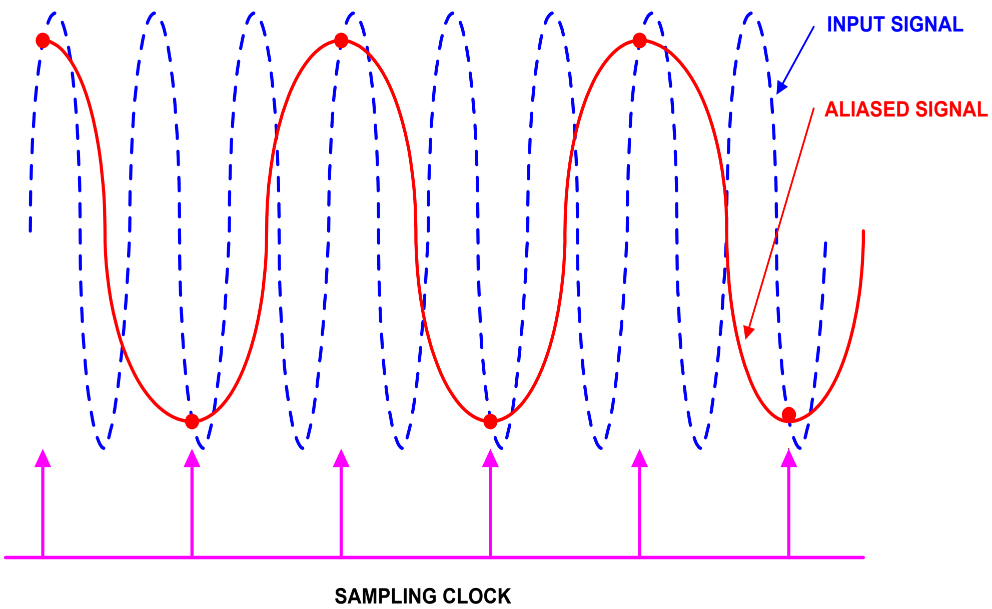


Broadband signals like pulses need to be sampled at 10 times the frequency of the waveform

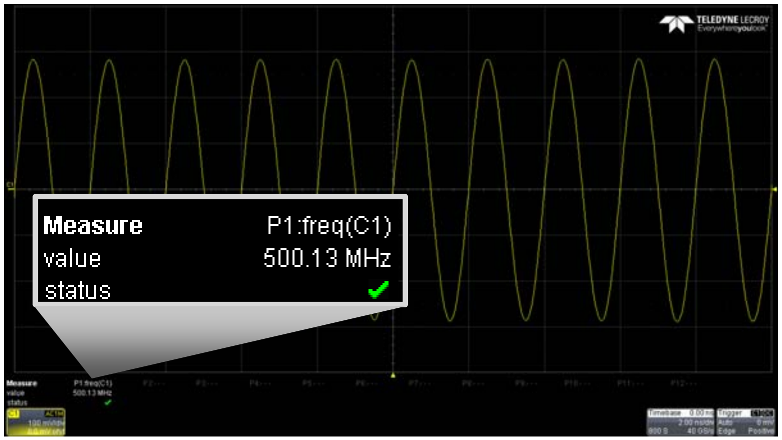
- The highest frequency that can be present in a digitized waveform is one half the sample rate
- 0.5 * Sample Rate = Nyquist Frequency
- Oversampling beyond Nyquist will improve signal fidelity and reduce noise
- Practical frequency limits of ¼ to 1/10 should be used depending on the nature of the waveform

Sampling Too Slowly Causes Aliasing

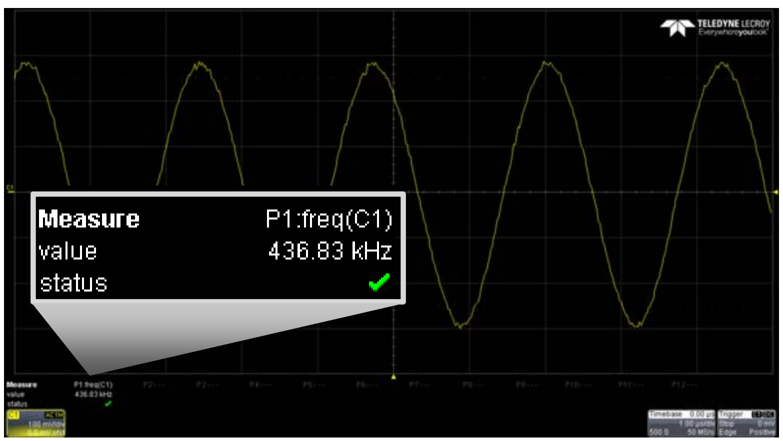
- If a signal is sampled at less than 2 times per cycle the DSO interprets the data as having a lower frequency. The resulting waveform is called an alias.
- The frequency of the alias is the difference frequency between the input signal and the sampling frequency or one of it's harmonics
- The aliased signal will appear to be poorly triggered and move horizontally



Which Measurement is Correct?



Clock Sampled at 40 GS/s



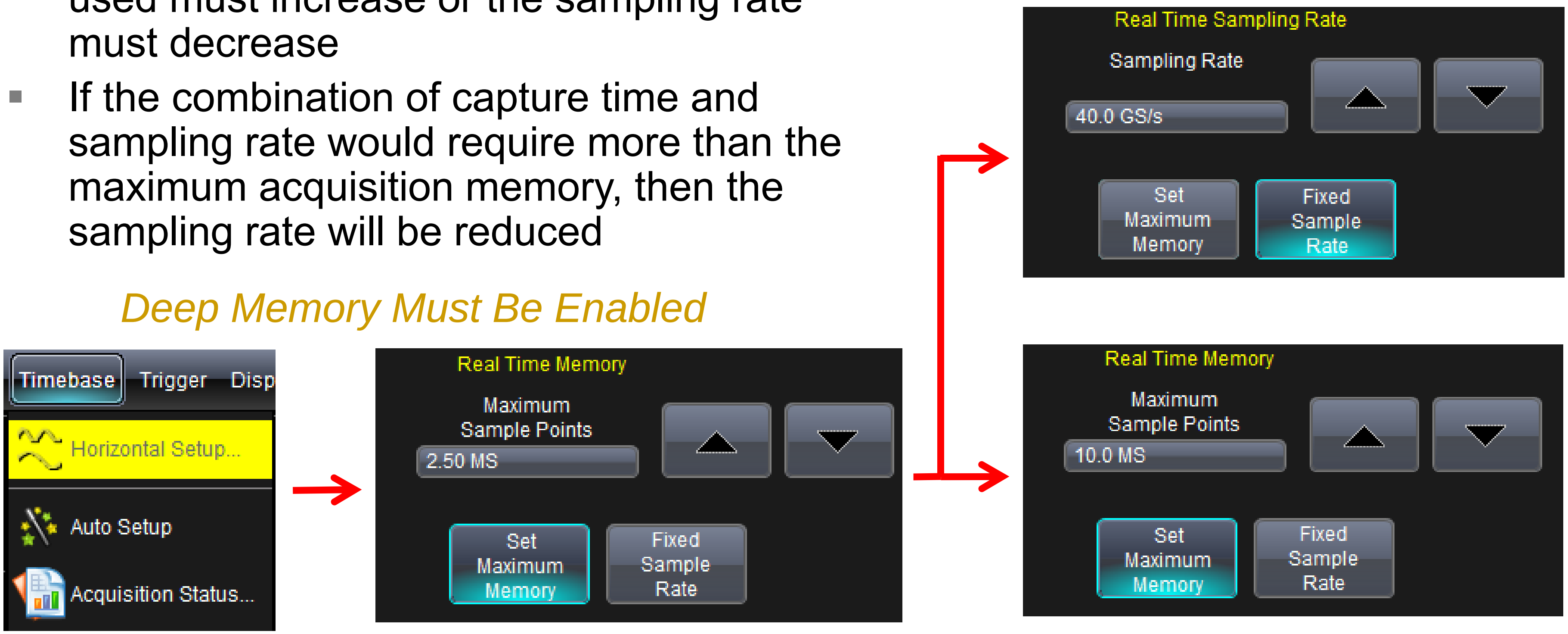
Clock Sampled at 50 MS/s

- The two waveforms look identical, but the measured frequencies are very different
- Clues to identify aliased waveform
  - Bottom waveform is not properly aligned with the trigger point
  - Is the frequency what you expected?
  - Is the sample rate at least 4x the expected waveform frequency?
- Lesson: Always keep an eye on the sampling rate!

Deep Memory Reduces Aliasing

- As the timebase is increased, the memory used must increase or the sampling rate must decrease
- If the combination of capture time and sampling rate would require more than the maximum acquisition memory, then the sampling rate will be reduced

Deep Memory Must Be Enabled

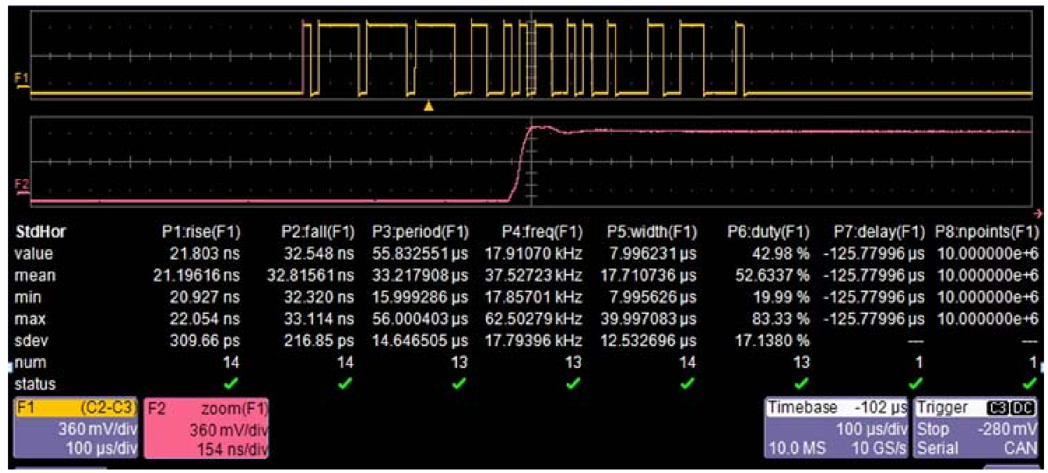


High Sample Rate for Edge Characterization

Signals that appear to be low speed can still have high frequency content and require high sample rate.

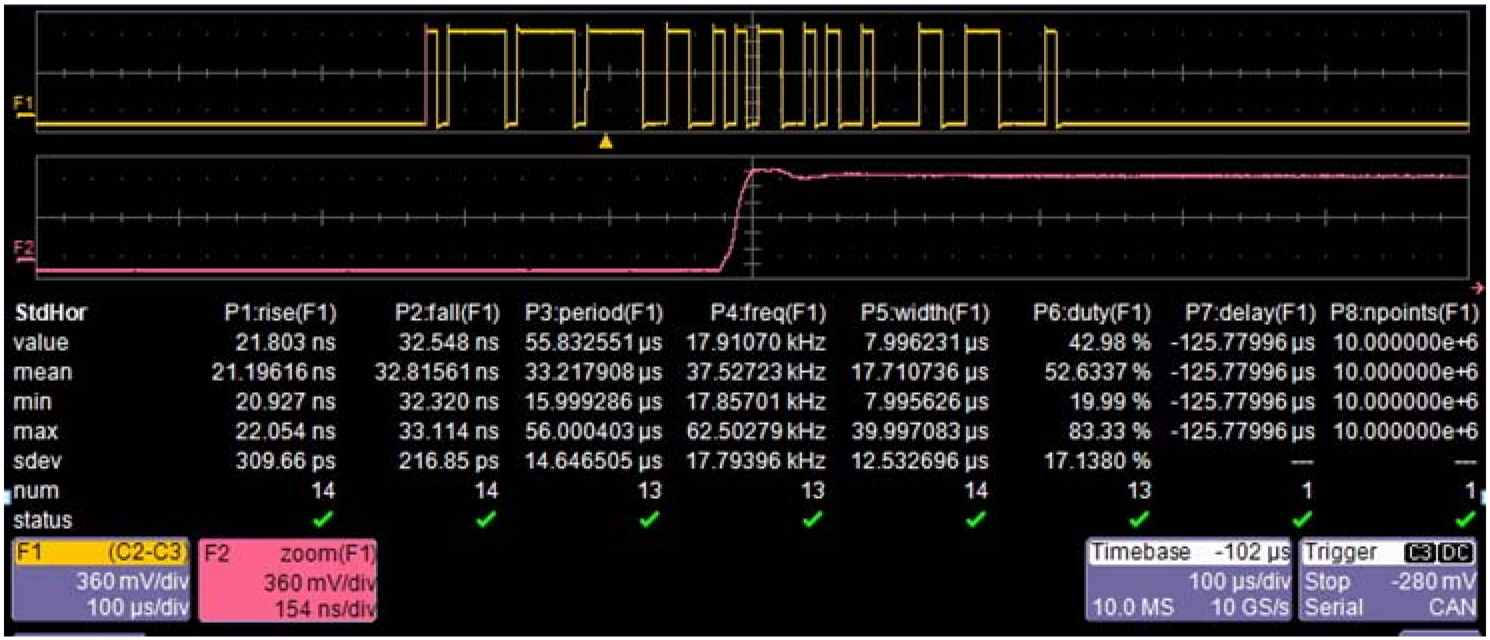
- Many digital signals have a low bit rate but a very fast rise time
- Necessary analog bandwidth to characterize edge can be calculated as
  Bandwidth = 0.35 / Rise Time
- Sample rate must be high enough to measure 4-5 samples on the edge

125 kb/s CAN signal with 21ns rise time



High Sample Rate for Edge Characterization

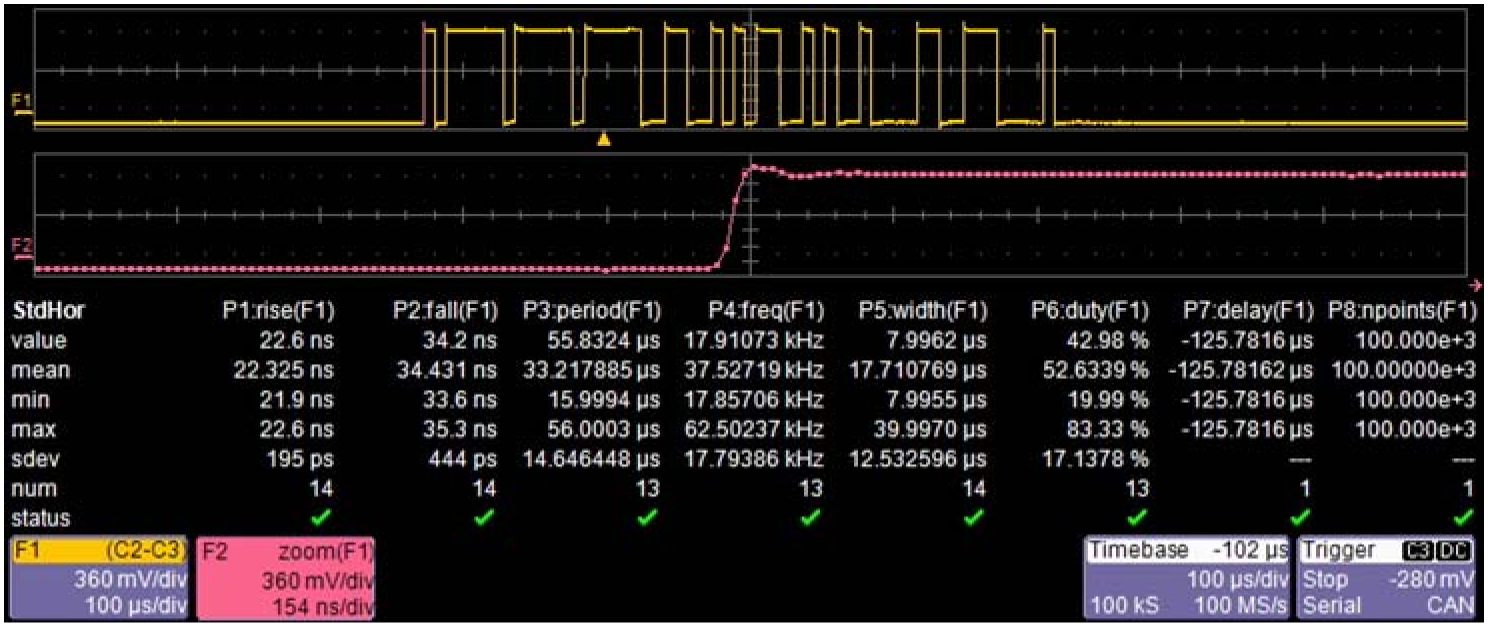
>100,000x Oversampled



Sample Rate = 10 GS/s **Measured Rise Time = 21.2 ns**

High Sample Rate for Edge Characterization

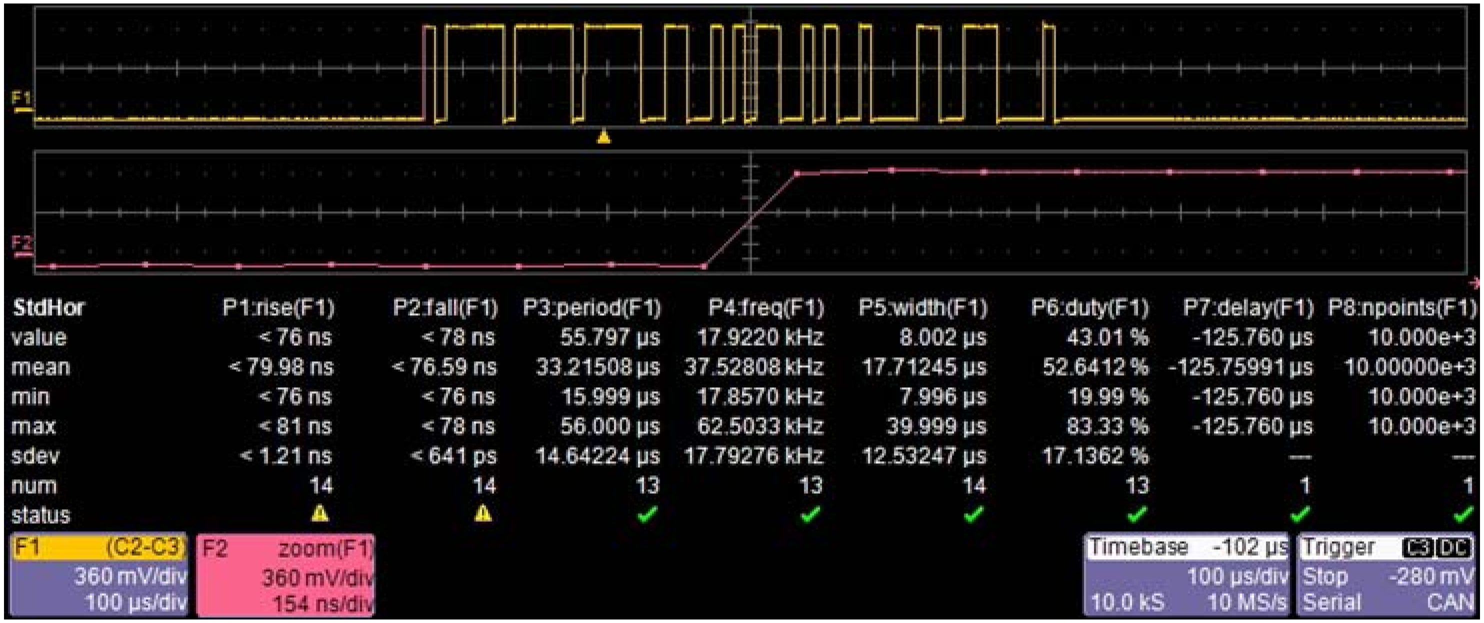
>1,000x Oversampled



Sample Rate = 100 MS/s　　**Measured Rise Time = 22.3 ns**

High Sample Rate for Edge Characterization

>100x Oversampled

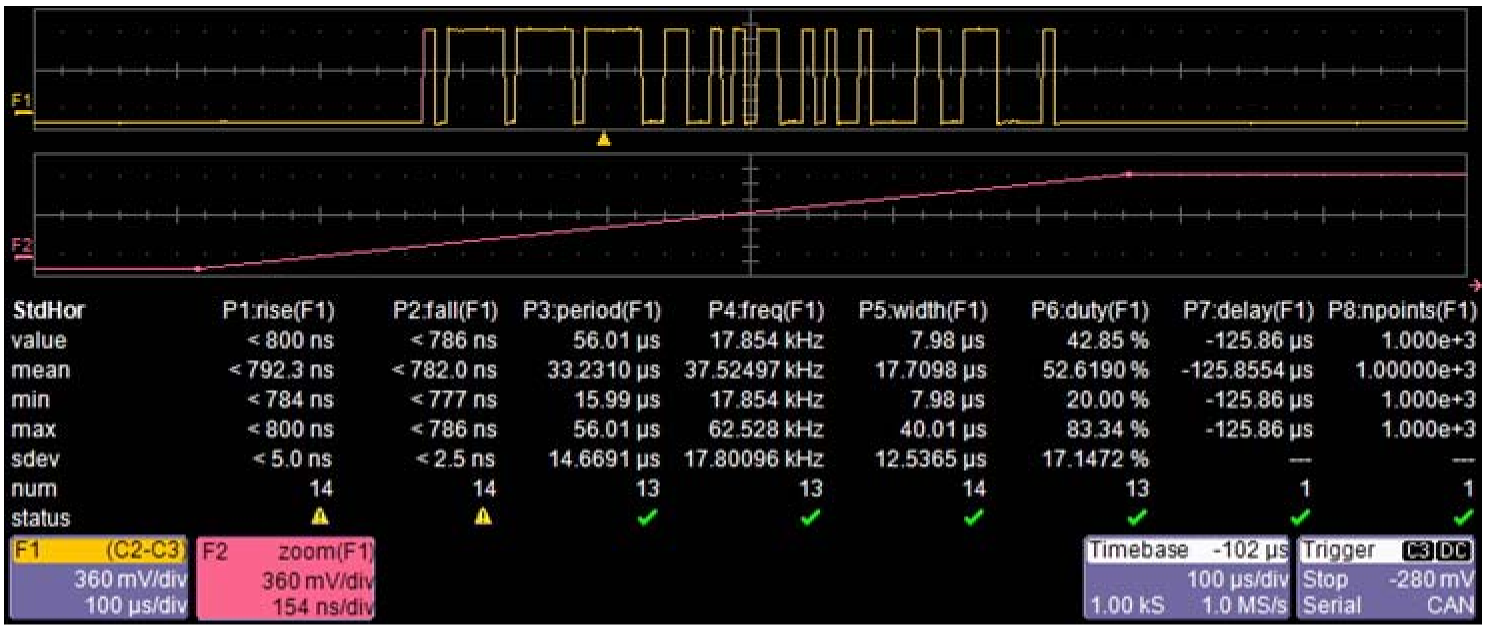


Sample Rate = 10 MS/s

Measured Rise Time = < 80.0 ns

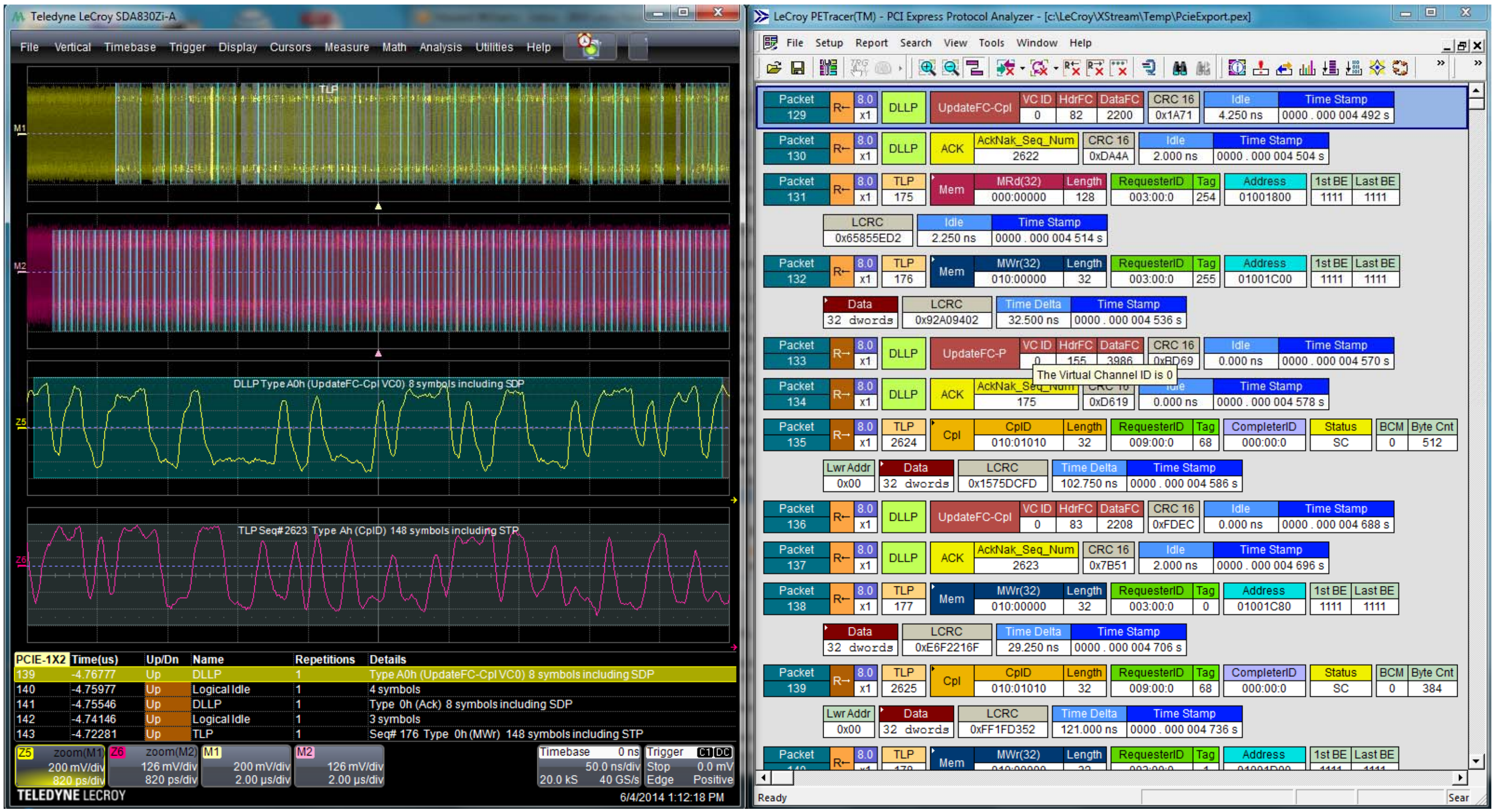
High Sample Rate for Edge Characterization

>10x Oversampled



Sample Rate = 1 MS/s **Measured Rise Time = < 792 ns**

Rule 4: Use Special Acquisition and Processing Modes When Appropriate



官方微博：http://weibo.com/lecroychina
官方微信：Teledyne_LeCroy

400-818-1288
Denny.li@teledynelecroy.com

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Thanks！