Measuring Multi-Gb/s Signals…
‘What type of Oscilloscope should I use??’

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A sampling oscilloscope or a real-time oscilloscope?

86100C “Equivalent-time” sampling oscilloscope

80000B “Real-time” oscilloscope
Oscilloscope Bandwidth

• Sufficient bandwidth is *essential* for an accurate waveform display

• Sampling scopes achieved 20 GHz bandwidths over 15 years ago!

• Over 80 GHz was achieved several years ago.
Bandwidth and sample rate

Real-time oscilloscopes sample at a rate faster than the signal being observed
  – Sample rates to 40 GSa/s
  – Bandwidths > 12 GHz

Equivalent-time (“sampling”) oscilloscopes sample at a rate slower than the signal being observed
  – Sample rates << 1 GSa/s
  – Bandwidths > 80 GHz
Extremely wide bandwidths at a low sample rate

A sample is taken, the data pattern repeats and the next sample is taken at a slight delay compared to the previous sample.
Extremely wide bandwidths at a low sample rate

In practice, samples are very close together (can be less than 100 fs apart). Through multiple passes of the signal, the waveform can be precisely reconstructed.
Sampling scope bandwidth is independent of the sample rate

Measurement bandwidth is affected by how narrow the sampler control pulse is (can be just a few picoseconds)

Since only one sample is taken, the A-D process can be very high resolution (up to 15 bits) with very low noise
Eye diagram construction with a sampling oscilloscope

PRBS

Re-Arm Time

Trigger Point

Sampling Point

Clock Trigger
Eye diagrams: Samples acquired with highly synchronous precision but at random locations in the data

Highly synchronous sampling at arbitrary bit locations
Eye diagrams can be generated for random as well as repeating data signals

MYTH!: “Sampling scopes can only display repetitive signals”
Real time Sampling: Entire Waveform in one Acquisition cycle

$S(t)$

- Nyquist criterion obeyed: $F_s > 2 \times \text{BW of signal}$
- Interpolation is used to precisely fill in points in between actual sampled points to yield better resolution
Oscilloscope Block Diagram

**Real Time Oscilloscope**

**Sampling Oscilloscope**
Post processing and data analysis

Search data for events-> glitch

Mathematical functions—> FFT, filters

Processing—> clock recovery

Eye diagrams

8b/10b Decoding

Jitter
Creating an Eye Diagram

Recovered clock

Data pattern

1, 4, 7, & 10 Overlaid

2, 5, 8, & 11 Overlaid

3, 6, 9, & 12 Overlaid

All Sections Overlaid
Capturing Waveforms

Vast capability in the ‘trigger’ space!

- Any Individual channel or from auxiliary source
- Positive going, Negative going Edges or ANY edge
- Any Logic between the channels
- Conditional ON or OFF state—pulse duration
- Glitch Triggering
- Specific analog event or software processing (Infiniscan)
Jitter Analysis

Compare a signal against a reference
Or analyze a clock signal against itself.

3 Key points:

1. Jitter analysis is about managing the Bit Error Ratio
2. Reference Signal generation
   - Explicit Clock given
   - SW Clock recovery
   - HW Clock recovery
3. Total Jitter Measurements on Oscilloscopes are *estimations*.

\[ (T_n - T_{n-1}) - (T_{n-2} - T_{n-3}) \]
\[ t_n - t_{n-N} \]
Jitter Analysis: Multiple Views

Real Time scopes Provide many views to aid understanding:

- Sampled Waveform
- Jitter Histogram
- Jitter Trend
- Jitter Spectrum

Jitter Analysis

- Acquire Waveform
- Threshold crossings
- Clock Recovery
- Evaluate Jitter values in time/freq

Jitter Separation

- Evaluate data dependent jitter
- Analyze RJ/PJ Histogram
- Combine for Total Jitter estimate
Jitter analysis with an equivalent time sampling oscilloscope

Advanced triggering system locks onto the pattern

Data dependent jitter: Walk scope through pattern to determine location of each edge versus ideal

Uncorrelated jitter: Look at any single edge and determine how it varies in position versus time. FFT of population yields RJ and PJ

PJ absolute amplitudes and frequencies also derived to rates ~data rate/4

RJ and DJ combined to precisely estimate TJ

(Extremely fast and accurate: For details, see Product note 86100C-1)
Signal path quality: Time Domain Reflectometer

Launch a *fast step* into the DUT

What reflected back?
- Returned voltage measured with wide bandwidth scope, indicates how much impedance changed

- What transmitted through?
  - Transmitted voltage measured with a wide bandwidth scope indicates the ’speed’ of the path

$$\text{200 mV}$$

(as fast as 10 ps)
TDR can be transformed into a Vector Network Analyzer

Time domain TDR/TDT

Transformed TDR to S-parameters
How do you decide which type of oscilloscope to use?

- Highest sample rate!
- Compliance testing!
- Widest Bandwidth!
- Best probing solution!
- Glitch capture!
“A scope is a scope!” Can you do it all with one?

An analogy: Power Saws

Circular saw

Table saw

Miter saw
Choosing the right type oscilloscope

Key question: What tasks are you trying to perform?

1) How much measurement BW is required and/or how precise does the waveform result need to be?
   
   – Anytime you change or reduce the frequency spectrum of a signal you will alter its time domain waveform shape
How fast can signals be before the scope bandwidth is a problem?

2.5 Gb/s waveform 20/80 risetimes

84 ps risetime

83 ps risetime

Real-time oscilloscope

Sampling oscilloscope
How fast can signals be before the scope bandwidth is a problem?

5 Gb/s waveform

40 ps risetime
33 ps risetime

Real-time oscilloscope
Sampling oscilloscope
How fast can signals be before the scope bandwidth is a problem?

10 Gb/s waveform

33 ps risetime

18 ps risetime

Real-time oscilloscope

Sampling oscilloscope
Choosing the right type oscilloscope

2) Observing small signals? Example: (18 mVpp, 5 Gb/s)

Real-time oscilloscope

Sampling oscilloscope
Troubleshooting and Probing

Could be this…

Or this…

But, more likely, something like this…
Signal Access

Remember:
1. The BW of measurement is determined by the lowest BW component.
2. Ensure the probes show what is there---NOT what could be!
Compliance Test

1. Select Your Test
2. Set Your Configuration
3. Connect Your Device as shown in the picture
4. Run the Test!

Test Selection Screen

Connection Screen

Test Results/Summary Screen

Agilent Offers Industry’s Largest Set of Application Packages
High-speed optical transmitters are generally tested with a “reference receivers”: A wide bandwidth photodetector combined with a 4th order Bessel-Thomson low pass filter.

Reference receiver frequency response must be precisely controlled.
Comparing the two systems strengths

**Equivalent-time oscilloscope**
- Bandwidth to > 80 GHz
- Data rates to > 50 Gb/s
- Time Domain Reflectometer
- Lowest Noise & Jitter
- High precision “long term” view
- Precision optical receivers
- Price

**Real-time oscilloscope**
- Sample rates to 40 GSa/s
- Complete Signal Access (Probing)
- High resolution short term capture
- Data rates to 8Gbs
- Rich and Flexible Triggering
- Low Noise with Noise/BW Reduction
Considerations in Selecting a Real time Oscilloscope

Your Goal:

Superior Signal Integrity and Probing for your Application

- Bandwidth
- Noise and Distortion Performance
- Probing Requirements and Probing Fidelity
- Memory
- Price
- Triggering
- Applications

Upgradeable BW from 2-13GHz

DSO81204B with industry leading noise floor at only 400μV
Considerations in Selecting a Sampling Oscilloscope

A wide bandwidth sampling oscilloscope is a modular instrument. Flexible configurations to match your test needs:

- Channel BW (20, 50, 70 or 80 GHz)
- TDR
- Optical receivers
- Hardware clock recovery
- Jitter Analysis
Complete Coverage with Both Sampling and Realtime Oscilloscopes

Sampling

- Most accurate waveform
- Lowest noise & jitter
- Impedance characterization
- Flexible configurations

Realtime

- Contiguous data set
- Rich triggering features
- Easiest in-circuit measurements
- Software clock recovery

Compliance Testing

Eye Diagram

Jitter
References

Product Note 86100-5: Triggering Sampling Oscilloscopes
Product Note 86100-6: Probing with Sampling Oscilloscopes
Product Note 86100C-1: Precision Jitter Analysis with 86100C Sampling Oscilloscope
Application Note 1556: Picking the Optimal Oscilloscope for Serial Data Signal Integrity Validation and Debug
DSO 80000B 2 to 13 GHz Real-time Oscilloscopes www.agilent.com/find/dso80000b
86100C DCA-J www.agilent.com/find/dca
Jitter Application info www.agilent.com/find/jitter-info