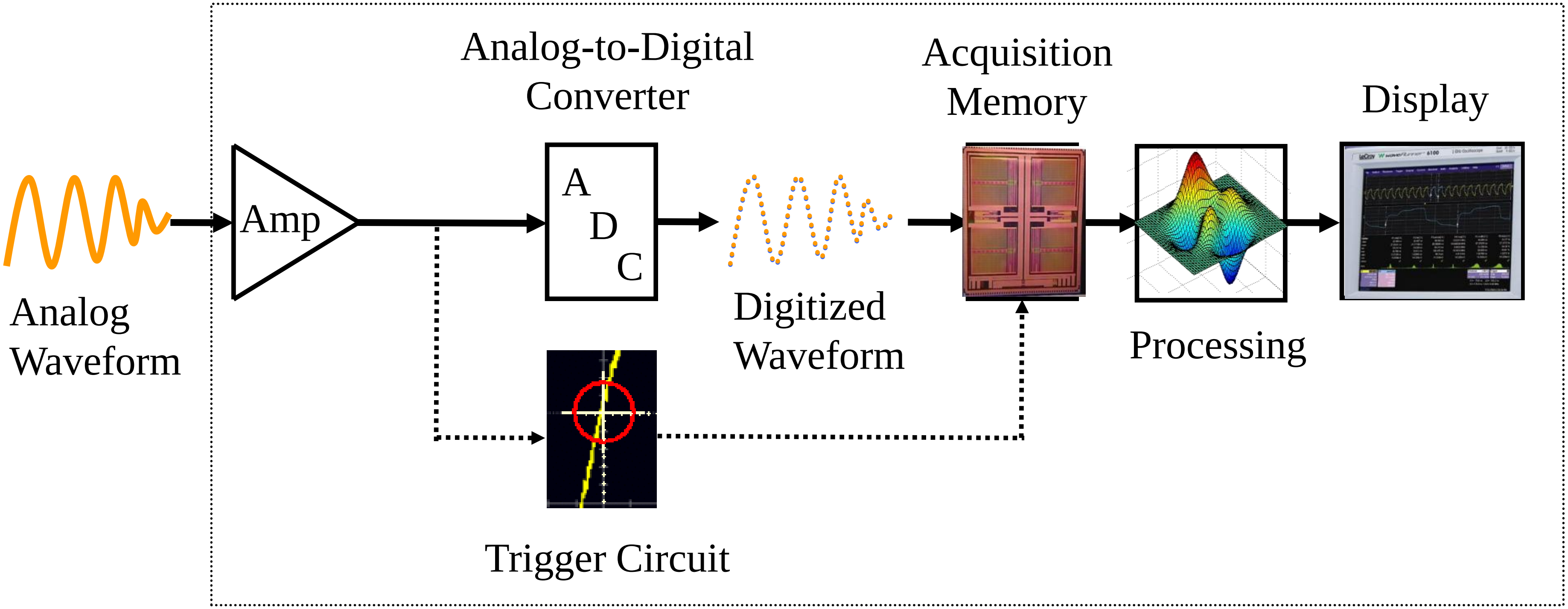
LeCroy

MAXIMIZING
PRODUCTIVITY
AND MEASUREMENT ACCURACY
WITH YOUR
DSO

Waveform Signal Path



Analog-to-Digital Converter

Acquisition Memory

Display

Amp

A D C

Analog Waveform

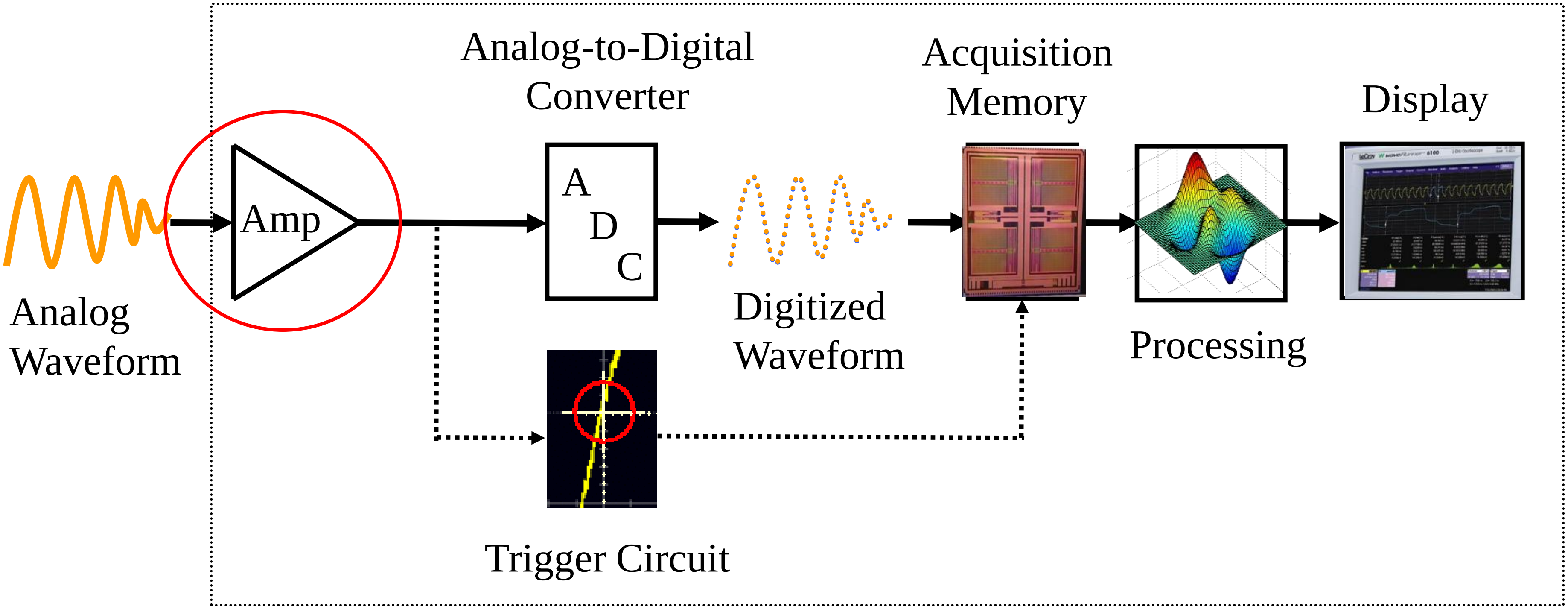
Digitized Waveform

Processing

Trigger Circuit

SIMPLIFIED OSCILLOSCOPE BLOCK DIAGRAM

Section 1: Analog Bandwidth



Analog Waveform

Amp

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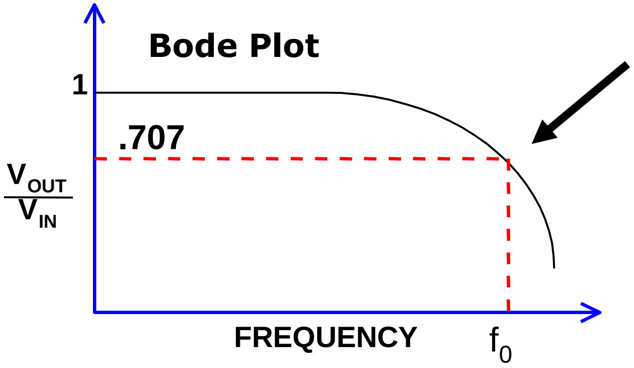
Section 1: Analog Bandwidth

Scope Analog Bandwidth

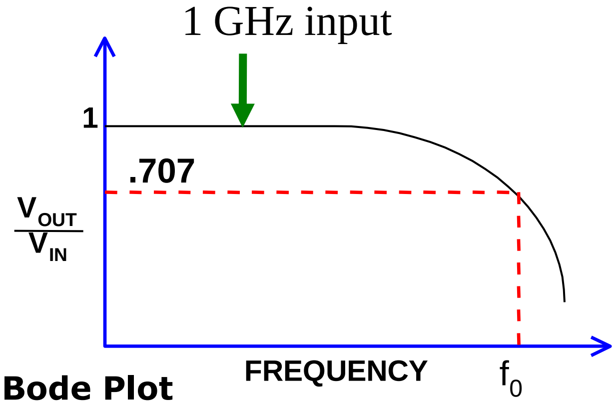
All oscilloscopes are specified with an analog bandwidth.



Analog bandwidth is the frequency at which the output falls to -3dB of the input

Scope Analog Bandwidth

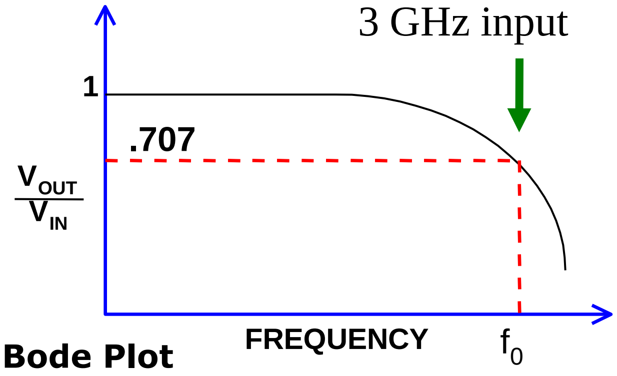
Example 1: A 3 GHz oscilloscope measures a **1 GHz** sine wave.



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.

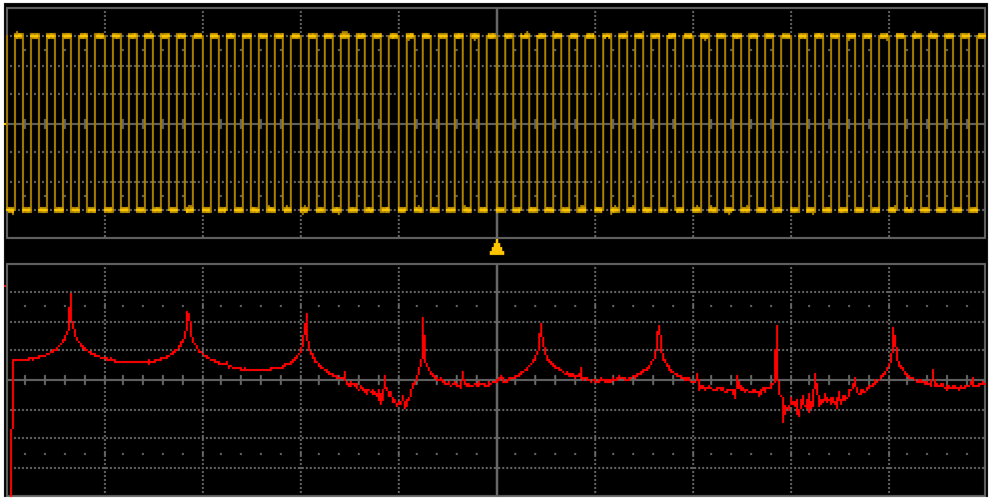


3 GHz, 1 V sinewave is input into oscilloscope

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

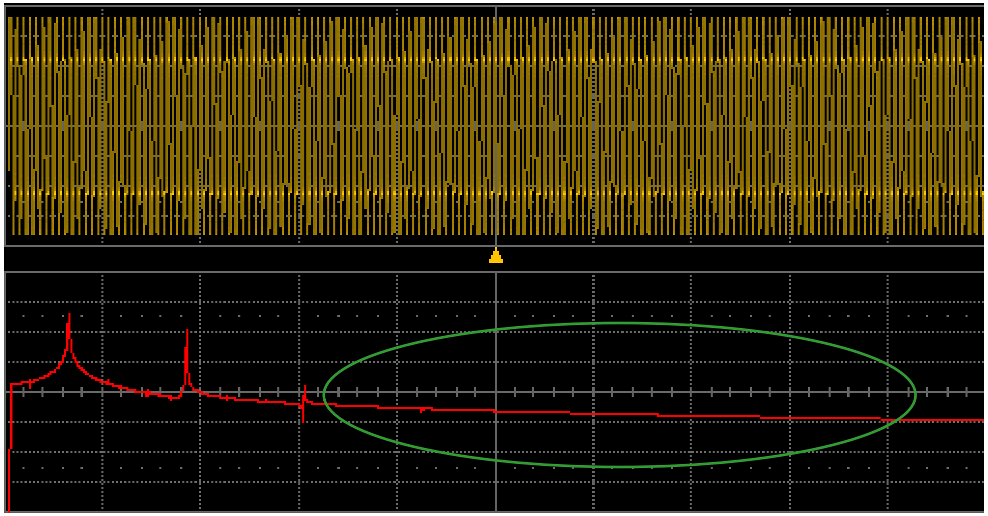
Scope Analog Bandwidth

Spectral View of Square Wave



Scope bandwidth at 1000x signal bandwidth

(Square Wave with 40% duty cycle)



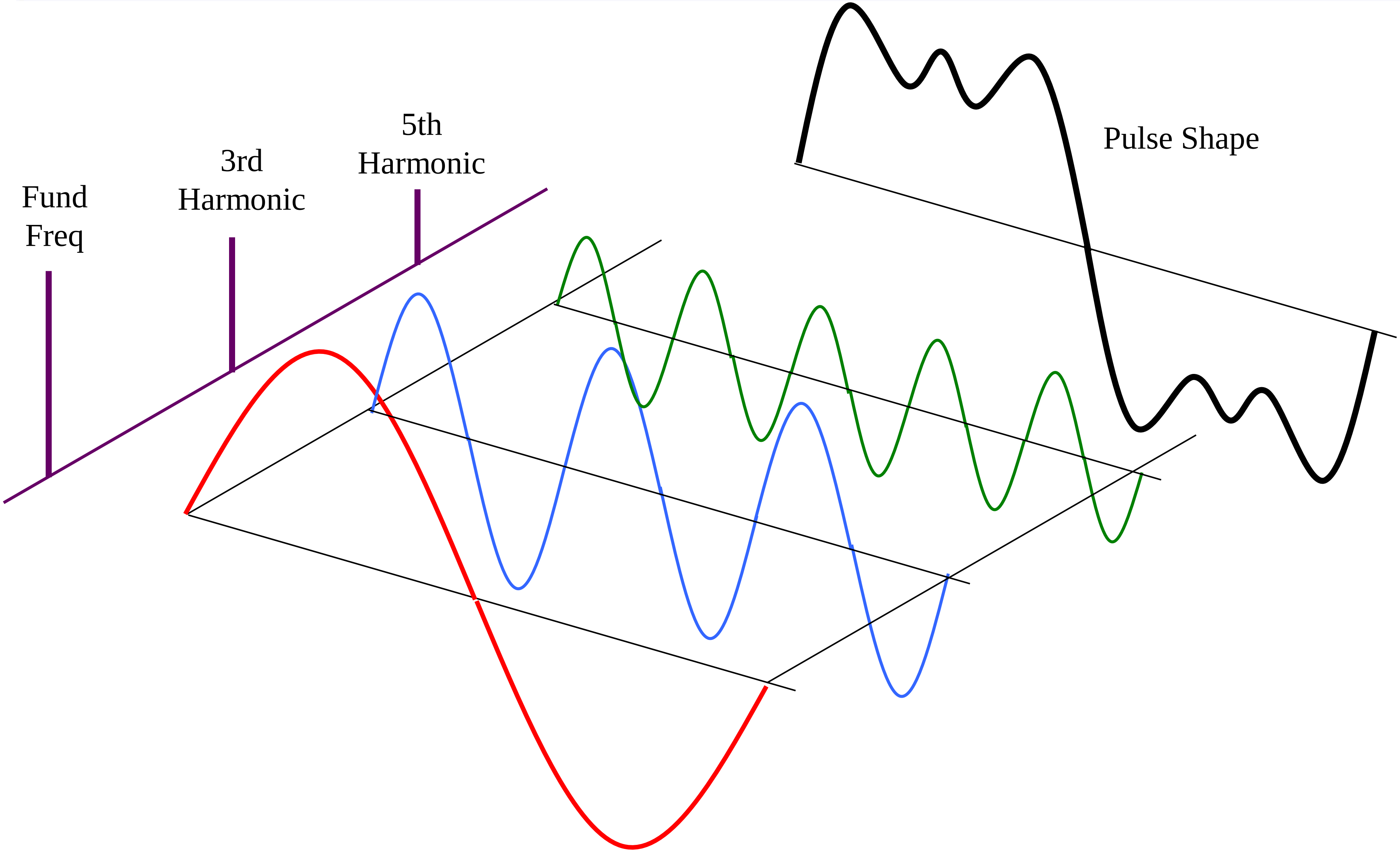
Scope bandwidth at 3x signal bandwidth

(Square Wave with 40% duty cycle)

Harmonics are attenuated (filtered) by scope

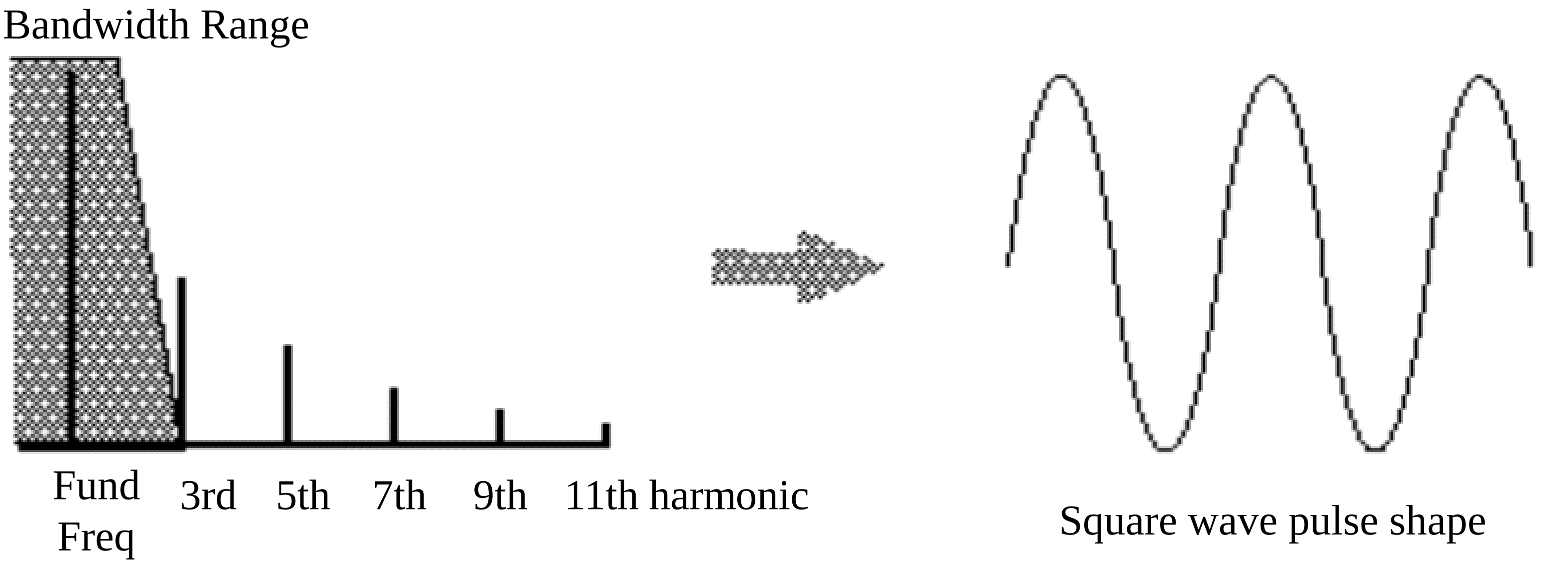
Scope Analog Bandwidth

Affects Pulse Shape Characteristics

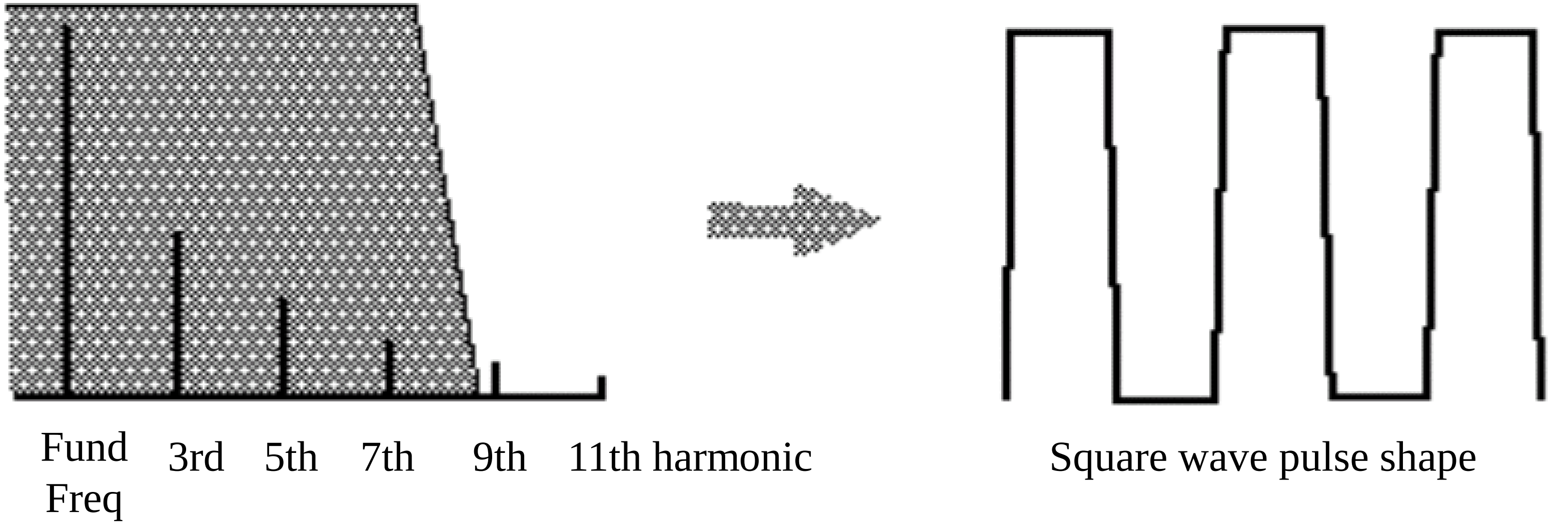


Scope Analog Bandwidth

Affects Pulse Shape Characteristics

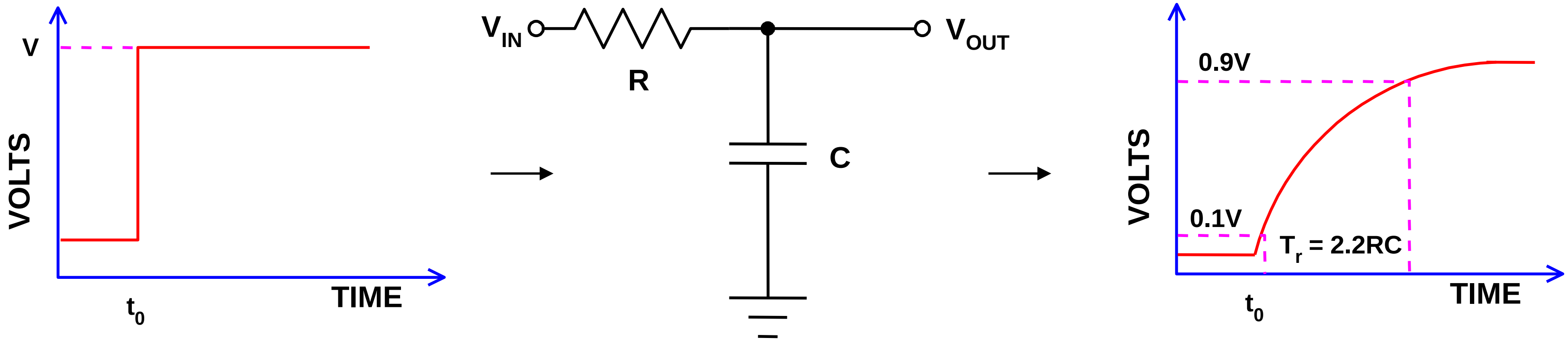


Square wave pulse shape



Square wave pulse shape

Relationship Between Risetime and Bandwidth



V_{IN} = STEP

Primitive 1-Pole Oscilloscope Model

$V_{OUT} = V(1 - e^{-T/RC})$

$$V_{OUT} = V(1 - e^{-T/RC})$$

$$V_{OUT} = V - V\, e^{-T/RC}$$

$$V - V_{OUT} = V\, e^{-T/RC}$$

$$e^{-T/RC} = \frac{V - V_{OUT}}{V}$$

$$-T/RC = LN\left(\left(V - V_{OUT}\right) / V\right)$$

$$\boxed{T = - RC * LN\left(\left(V - V_{OUT}\right) / V\right)}$$

$$T_{90\%} = - RC * LN\left(\left(V - 0.9\, V \right) / V\right)$$

$$T_{90\%} = - RC * LN(1 - 0.9) = - RC * LN(0.1) = 2.3\, RC$$

$$T_{10\%} = - RC * LN\left(\left(V - 0.1\, V \right) / V\right)$$

$$T_{10\%} = - RC * LN(1 - 0.1) = - RC * LN(0.9) = 0.1\, RC$$

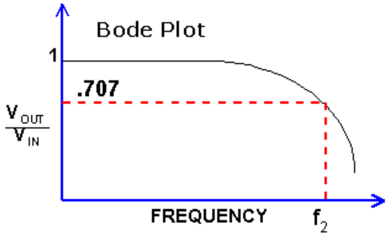
$$T_{rise} = T_{90\%} - T_{10\%} = 2.2\, (RC) = 2.2/2\pi f = 0.35 / f$$

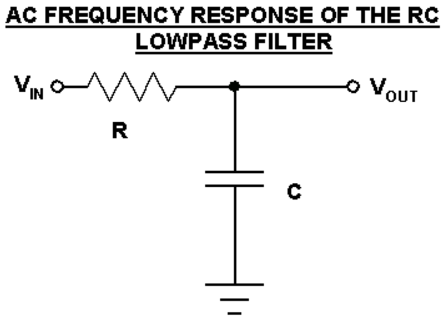
$$\boxed{\text{Risetime} = (0.35) / \text{Bandwidth}}$$

(for a single-pole RC approximation)

Actual Oscilloscope Frequency Response

Modern oscilloscopes can no longer be modeled as a simple one-pole RC filter

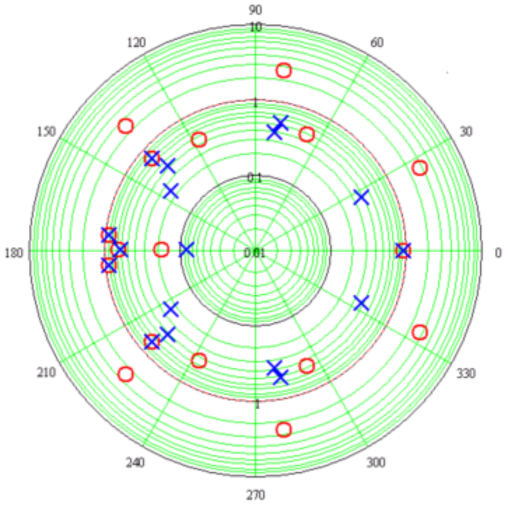


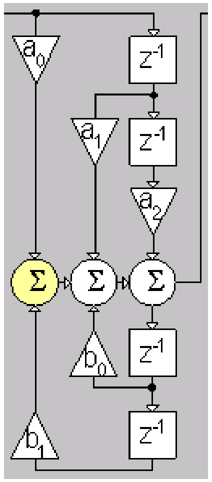


Typical modern oscilloscopes front end design

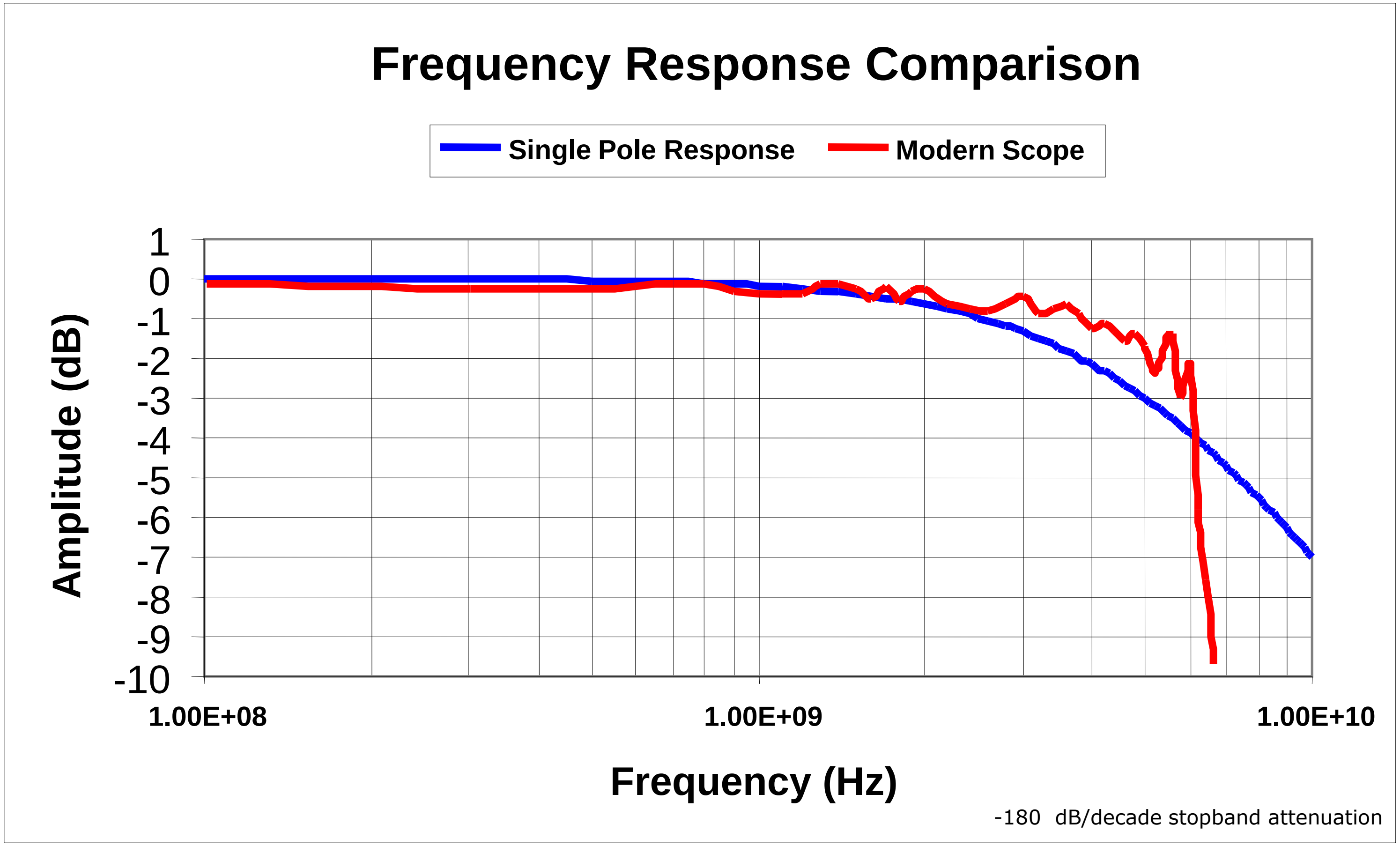
Typical DSO Bode Plot

S-domain: 17 poles, 17 zeros





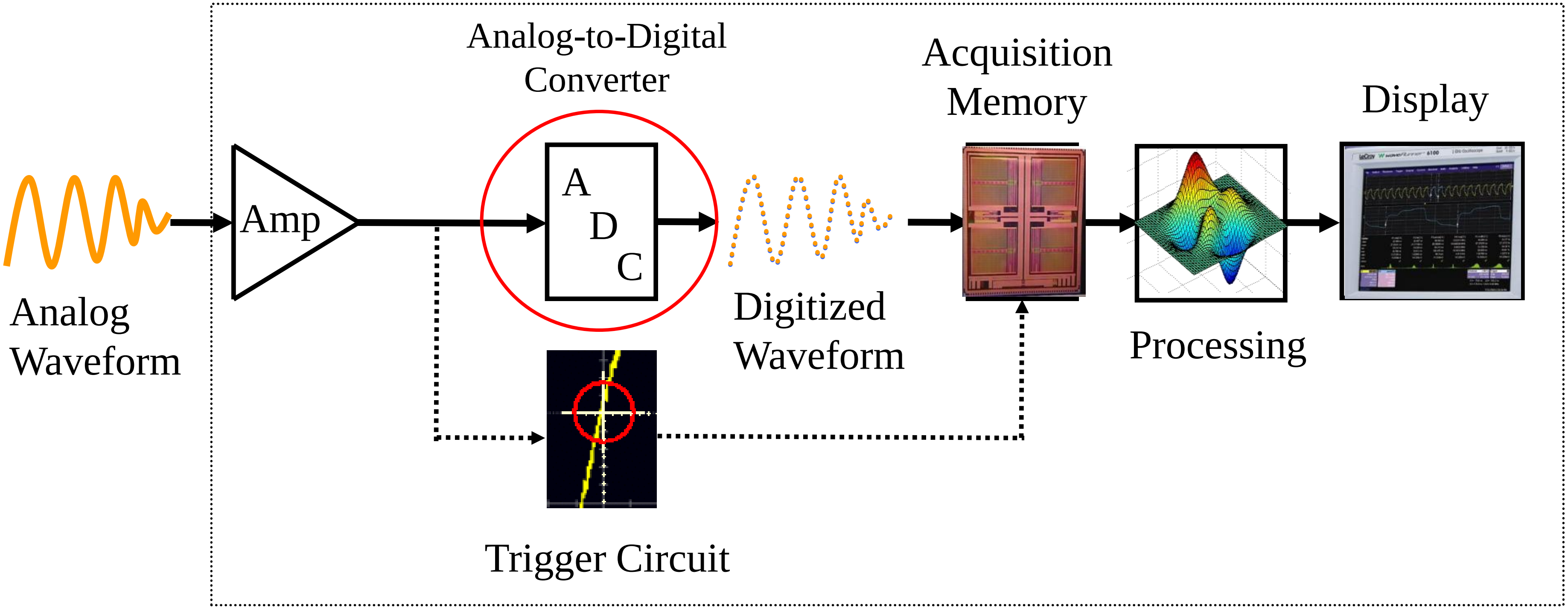
Modern Scope Bandwidth and Risetime



Risetime = 0.45/Bandwidth

E.g.: 6 GHz scope bandwidth, 75 ps scope risetime

Section 2: Sampling Rate



Analog-to-Digital Converter

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Analog Waveform

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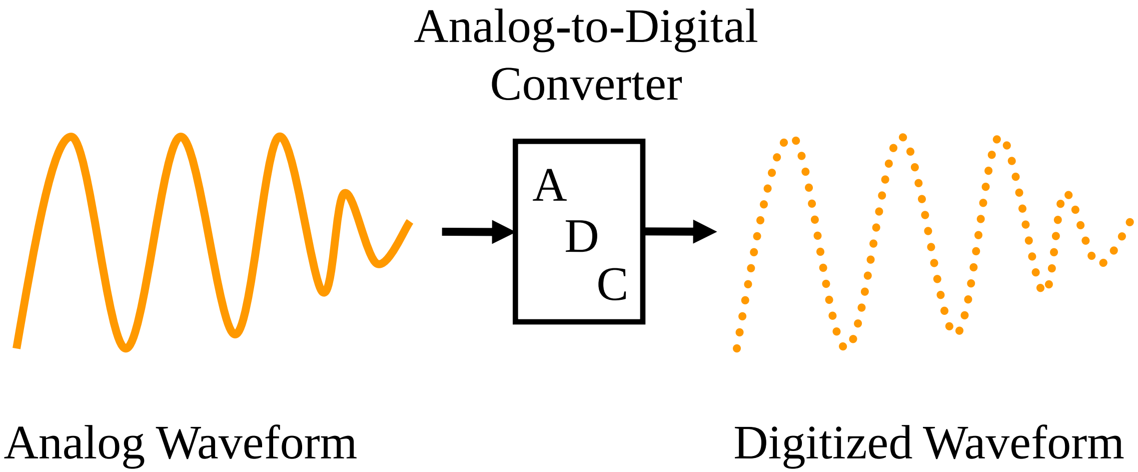
Section 2: Sampling Rate

Bandwidth and Sample Rate

Definition of Bandwidth: Bandwidth is the maximum signal frequency that can be input into the scope with no more than -3dB attenuation

Definition of Sample Rate: Sample rate is the speed at which the scope can digitize and record the voltage level of an input signal

ADC Outputs Digitized Samples

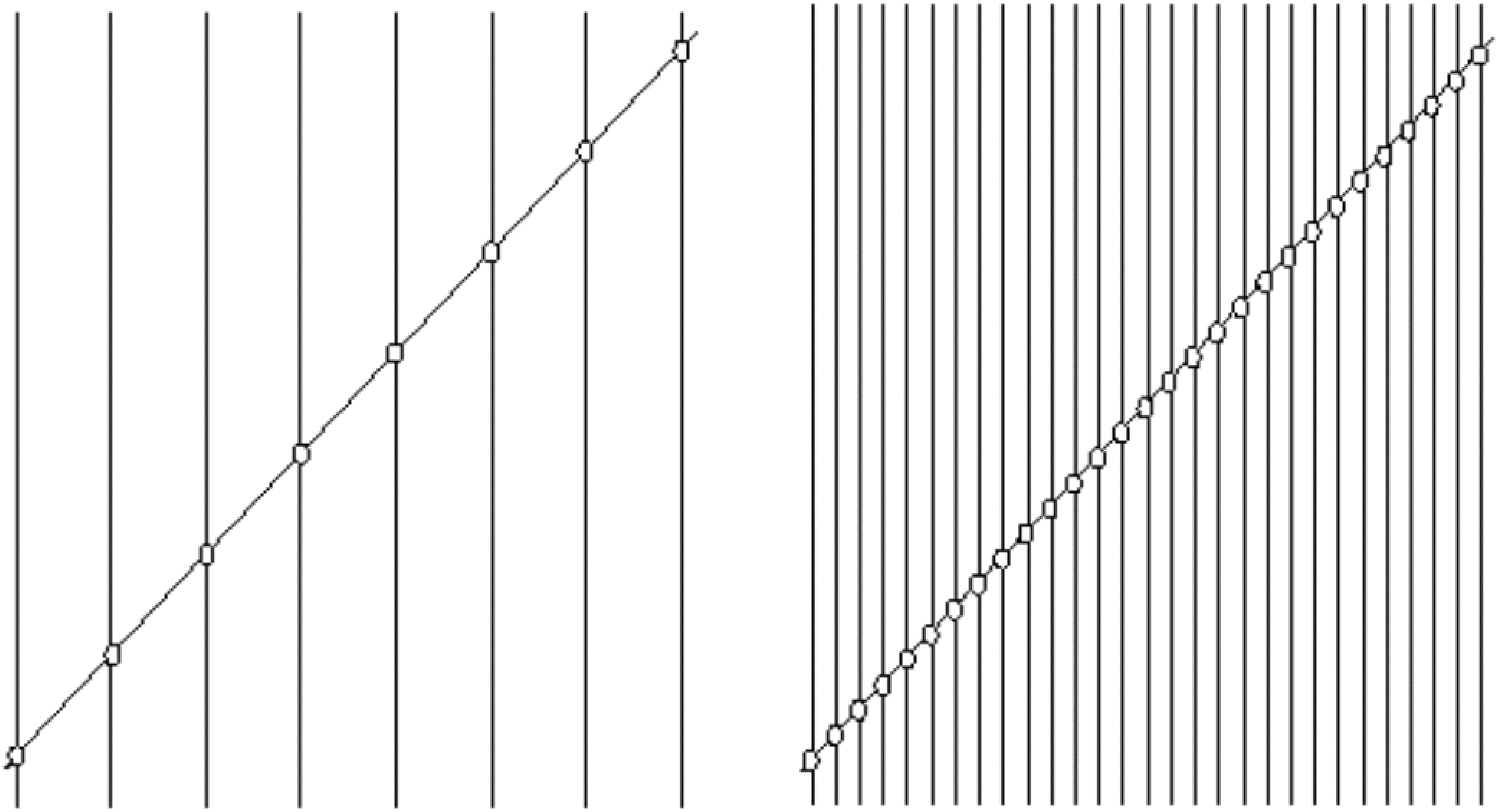


Analog-to-Digital
Converter

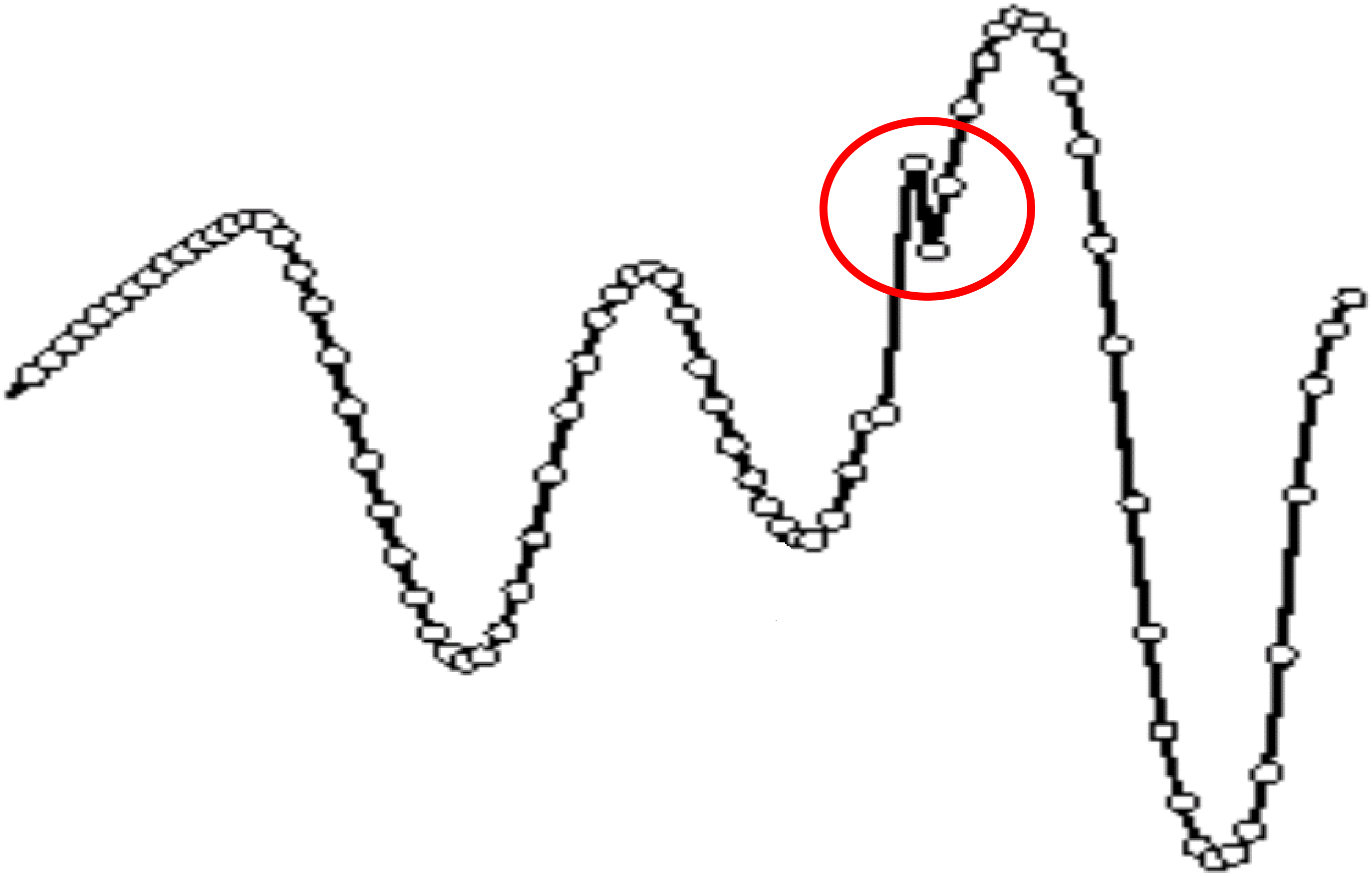
Analog Waveform

Digitized Waveform

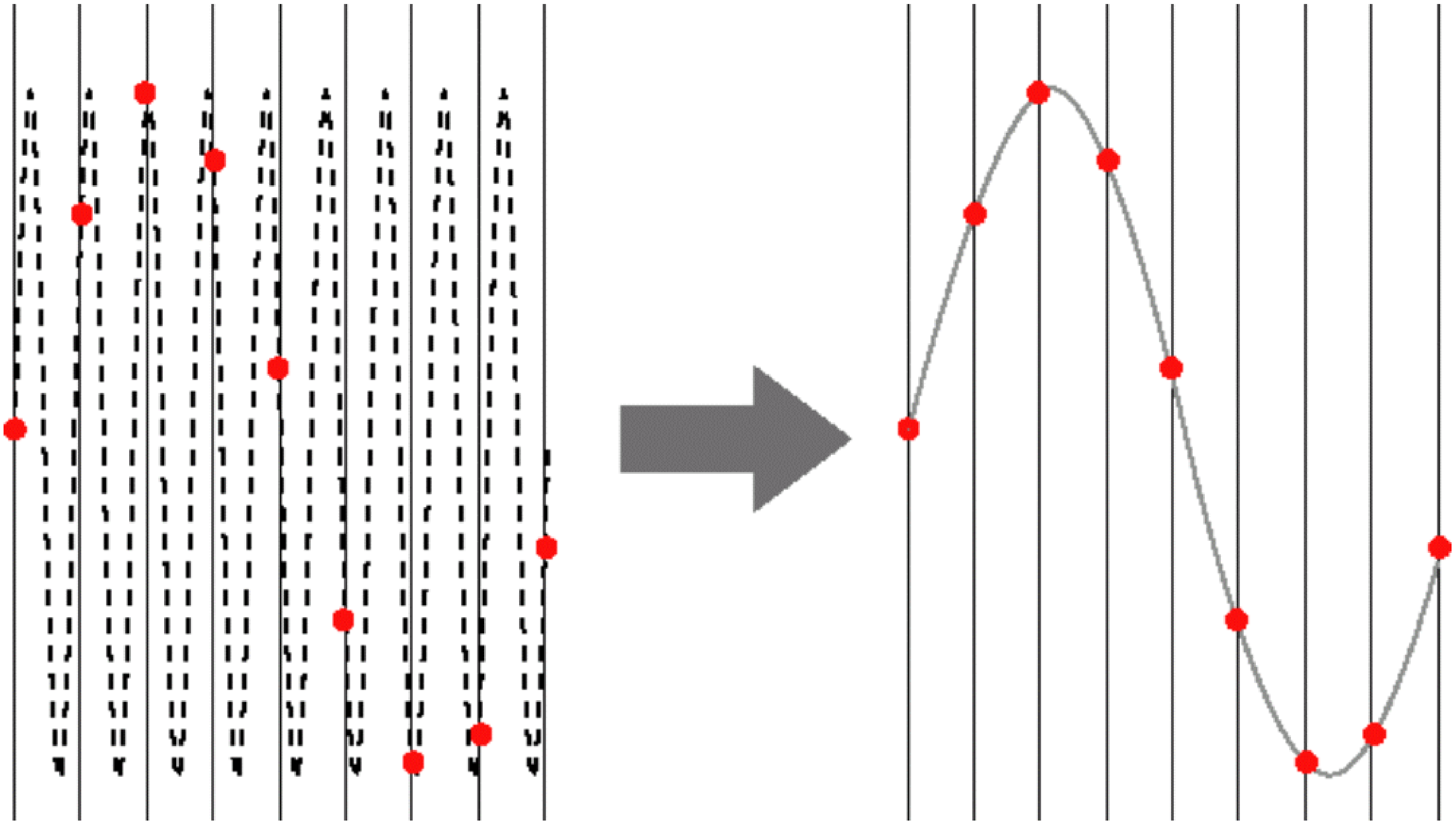
Effect of Sample Density on Ramp



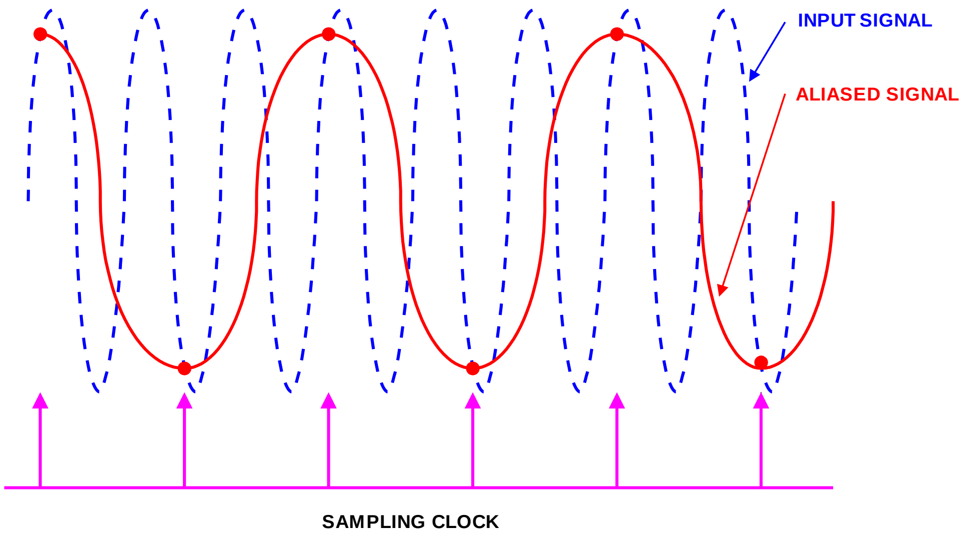
Effect of Sample Density on Intermittent Events



Aliasing

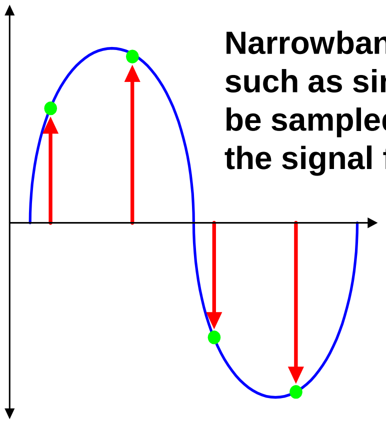


Aliasing: Sampling Too Slowly

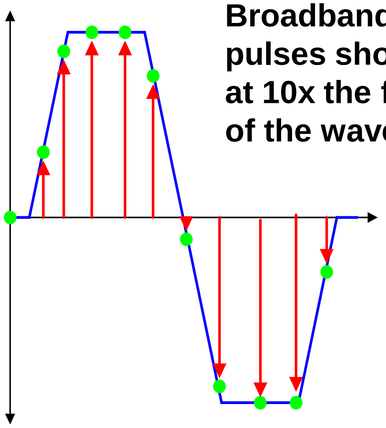


If a signal is sampled at less than 2 times per cycle the DSO interprets the data as having a lower frequency which is called an alias. The frequency of the alias is the difference frequency between the input signal and the sampling frequency or one of its harmonics. The aliased signal will also appear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

The highest frequency that can be present in a digitized waveform is one half the sample rate – this is the theoretical digital bandwidth of the waveform

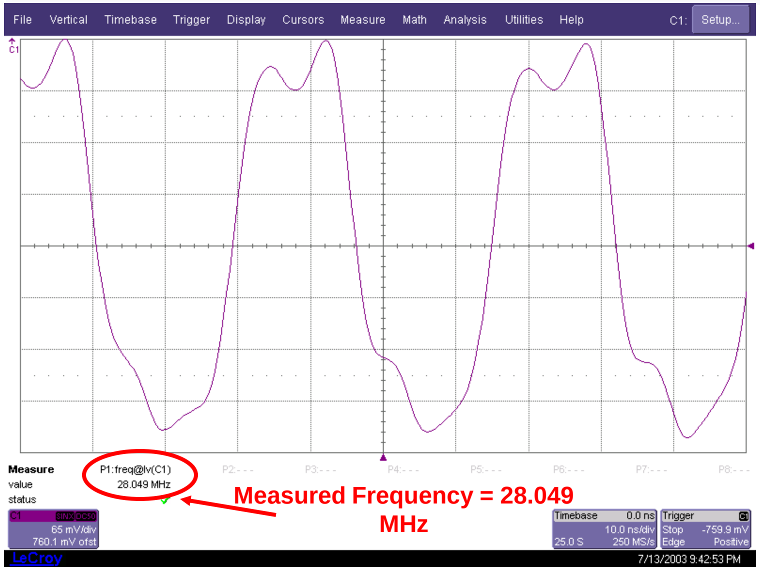


Narrowband waveforms such as sine waves should be sampled at 2x - 4x the signal frequency



Broadband signals like pulses should be sampled at 10x the frequency of the waveform

Which measurement is correct?



Measure P1:freq@lv(C1)
value 28.049 MHz
status ✓

C1 SINX DC50
65 mV/div
760.1 mV ofst

Timebase 0.0 ns
10.0 ns/div
25.0 S 250 MS/s

Trigger C1
Stop -759.9 mV
Edge Positive

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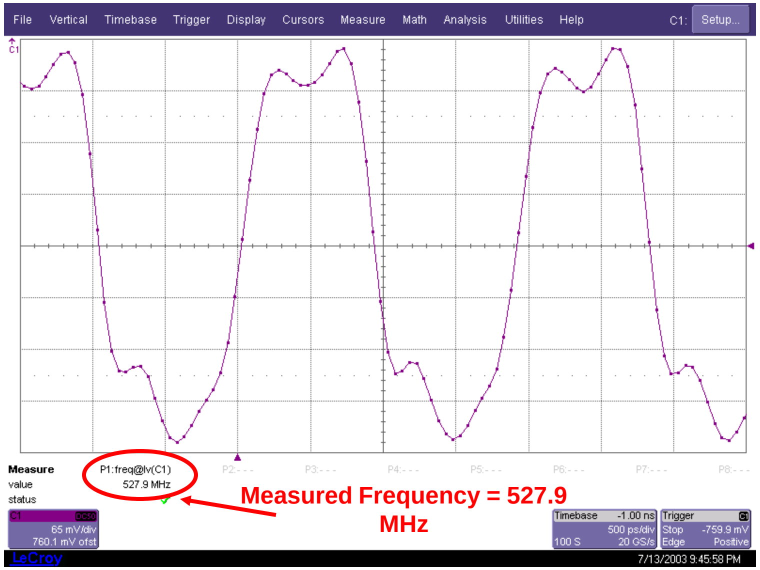
Measured Frequency = 28.049 MHz

Clock Sampled at 250 MS/s



Measure P1:freq@lv(C1)
value 527.9 MHz
status ✓

C1 DC50
65 mV/div
760.1 mV ofst

Timebase -1.00 ns
500 ps/div
100 S 20 GS/s

Trigger C1
Stop -759.9 mV
Edge Positive

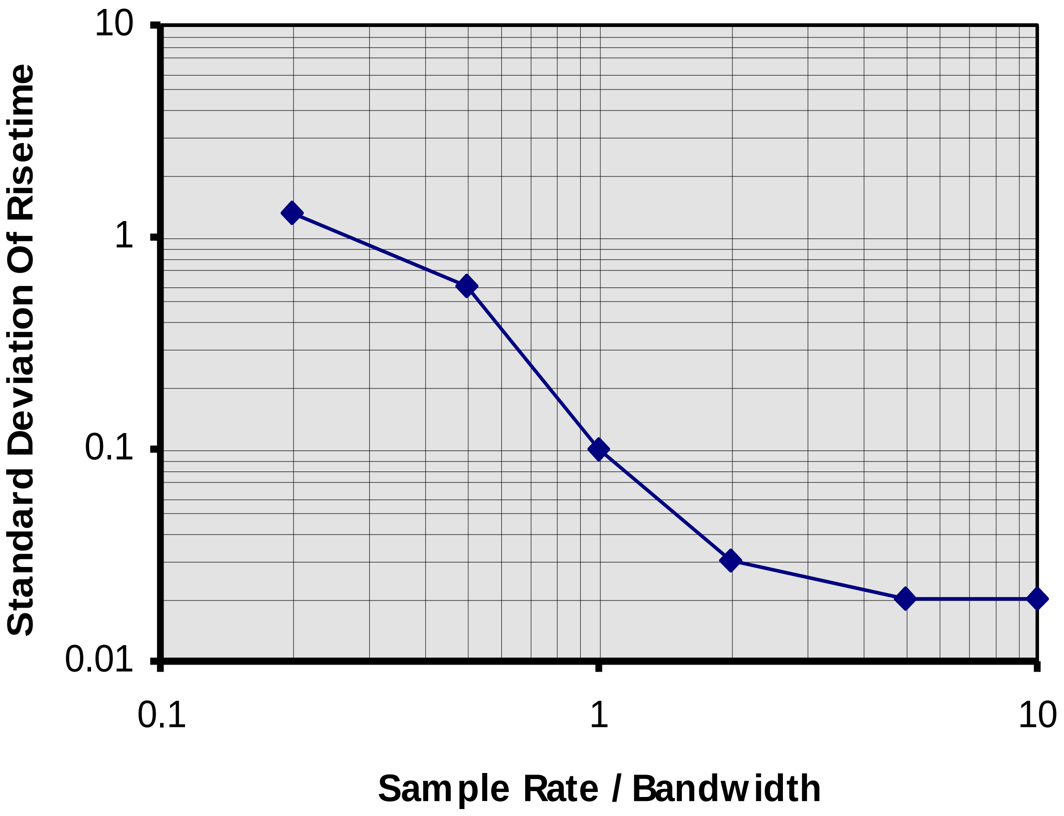
7/13/2003 9:45:58 PM

Measured Frequency = 527.9 MHz

Clock Sampled at 20 GS/s

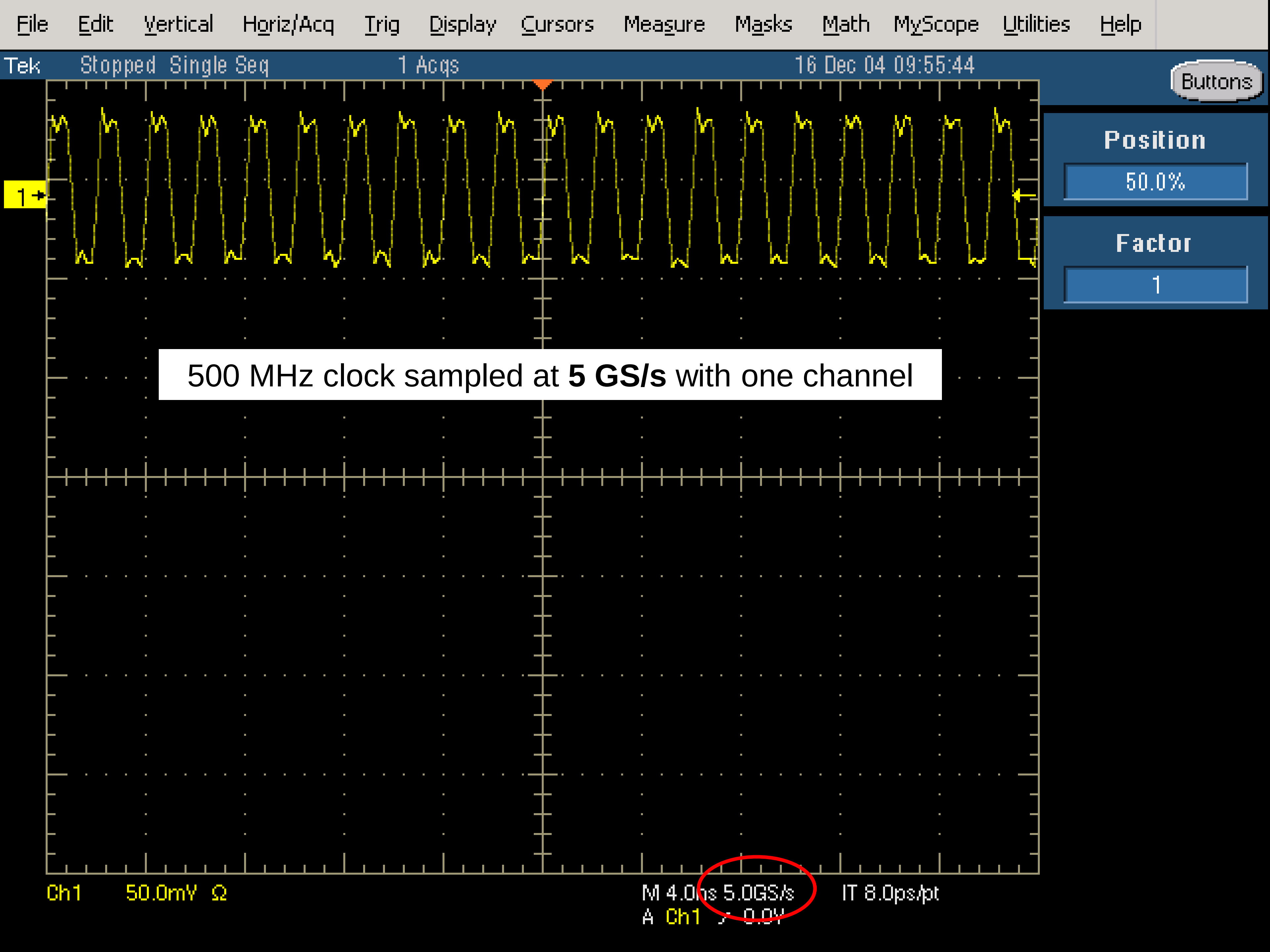
- The two waveforms look identical, but the measured frequencies are very different
- Clues identify aliased waveform:
  - Top waveform is not properly aligned with the trigger point
  - Frequency measured in top trace is approximately the frequency of the bottom trace less two times the sampling frequency
- Note the sampling rate

Why is Oversampling Important?



Sample Rate	Time/ Pt	SR/BW	Avg. Rise Time	sdev
200 MS/s	5 ns	0.2	4.7 ns	1.3 ns
500 MS/s	2 ns	0.5	2.3 ns	0.6ns
1 GS/s	1 ns	1.0	1.6 ns	0.1 ns
2 GS/s	0.5 ns	2.0	1.27 ns	0.03 ns
5 GS/s	0.2 ns	5.0	1.16 ns	0.02 ns
10 GS/s	0.1 ns	10.0	1.15 ns	0.02 ns

- You must sample at greater than 5x the bandwidth to achieve good measurement accuracy
- Higher sampling rates return less reduction in uncertainty



500 MHz clock sampled at **5 GS/s** with one channel

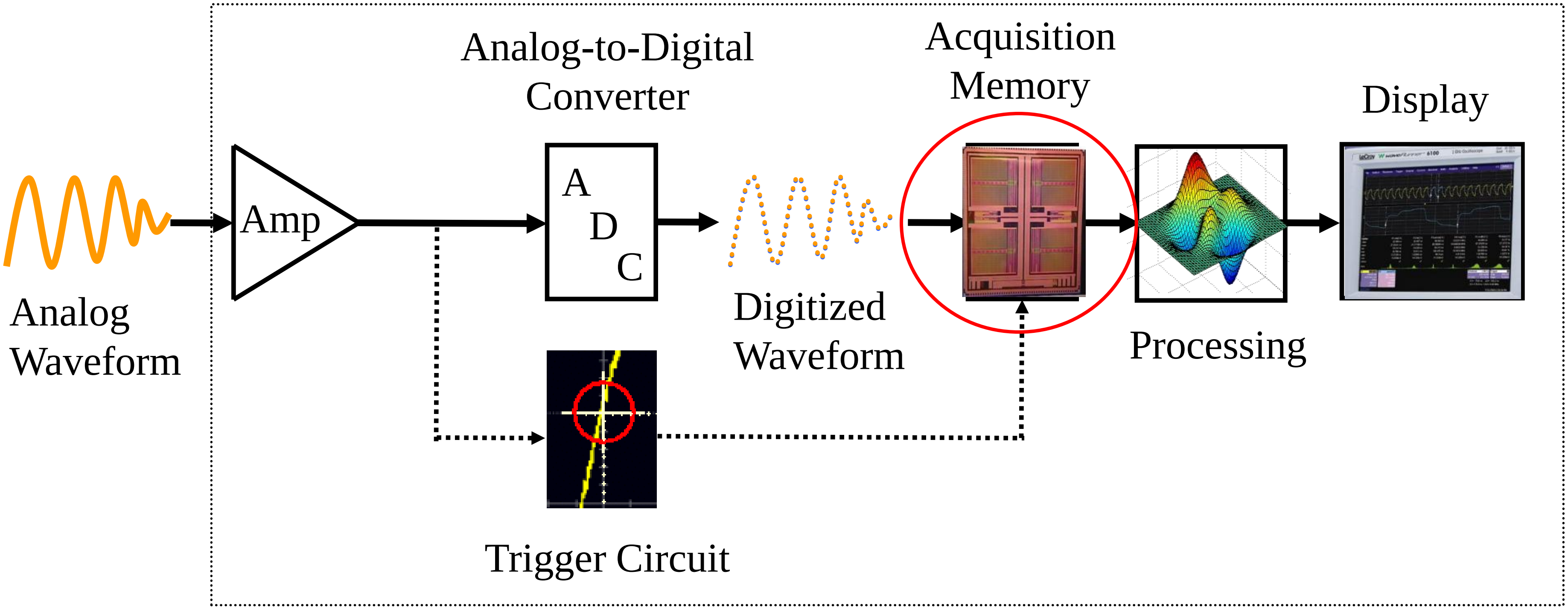
Pulse shape distortion results from undersampling of this 500 MHz clock signal at 1.25 GS/s

```
Tek   Stopped  Single Seq        1 Acqs              16 Dec 04 10:48:00
```

```
Rise(C1)!        630.6ps
μ: 630.6169p
m: 630.6p        M: 630.6p
σ: 0.0           n: 1.0
Fall(C1)!        1.088ns
μ: 1.0875921n
m: 1.088n        M: 1.088n
σ:               n: 1.0
Ampl(C1)!        67.0mV
μ: 67.0m
m: 67.0m         M: 67.0m
σ:               n: 1.0
Freq(C1)!        441.7MHz
μ: 441.70624M
m: 441.7M        M: 441.7M
σ:               n: 1.0
```

```
Ch1    50.0mV  Ω        Ch2    50.0mV        M 2.0ns 1.25GS/s     IT 4.0ps/pt
Ch3    50.0mV           Ch4    50.0mV        A  Ch1  ╱  0.0V
```

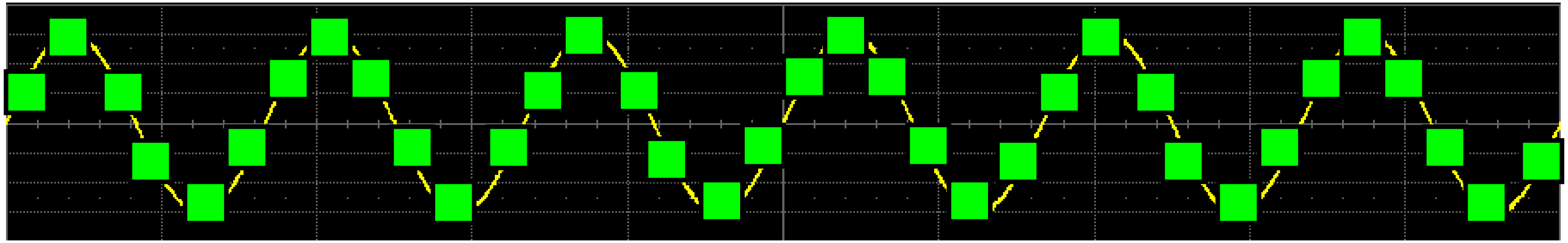
Section 3: Acquisition Memory



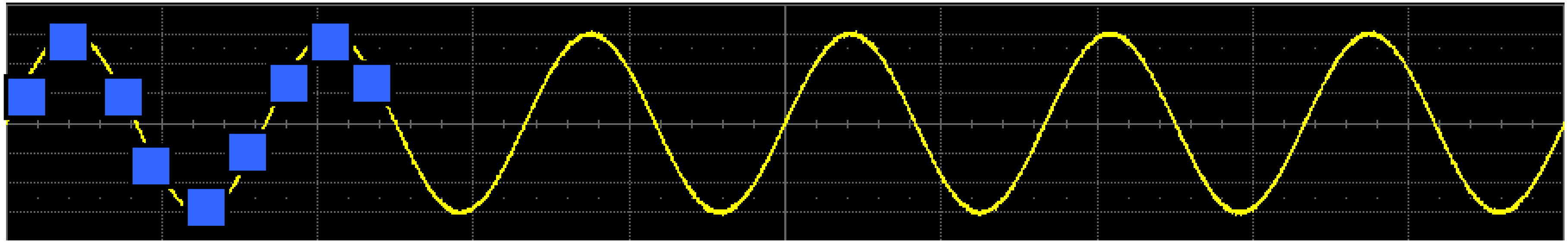
Section 3: Acquisition Memory

Memory's Effect On Signal Integrity

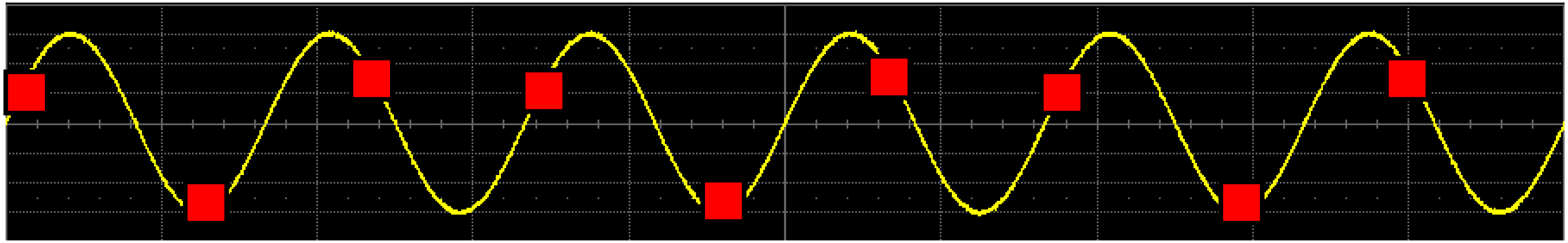
Long memory record: Correctly sample **all** of the data



Short memory record: Correctly sample **part** of the data

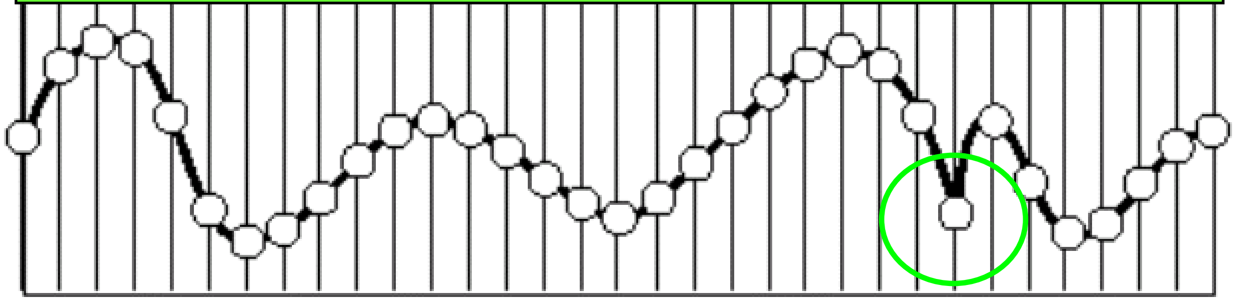


Short memory record: **Incorrectly** sample all of the data

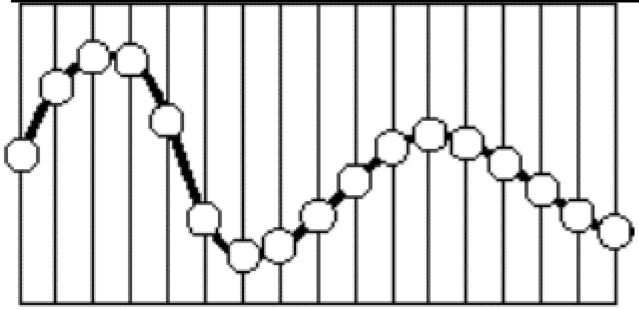


Memory's Effect On Glitch Detection

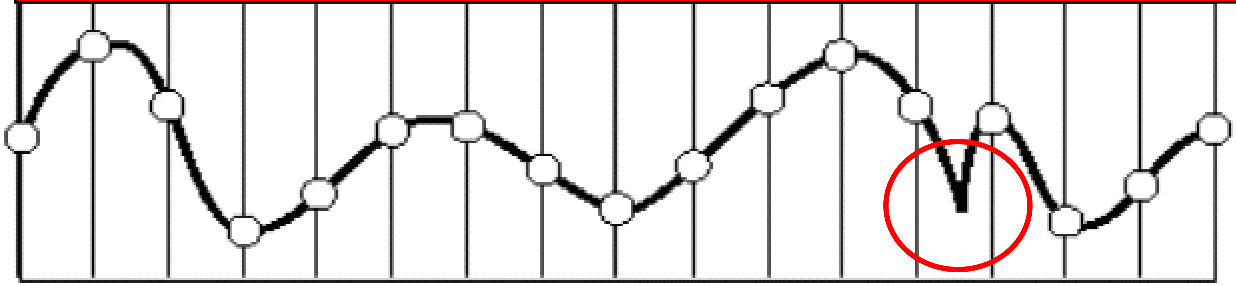
Long memory record: Correctly sample **all** of the data



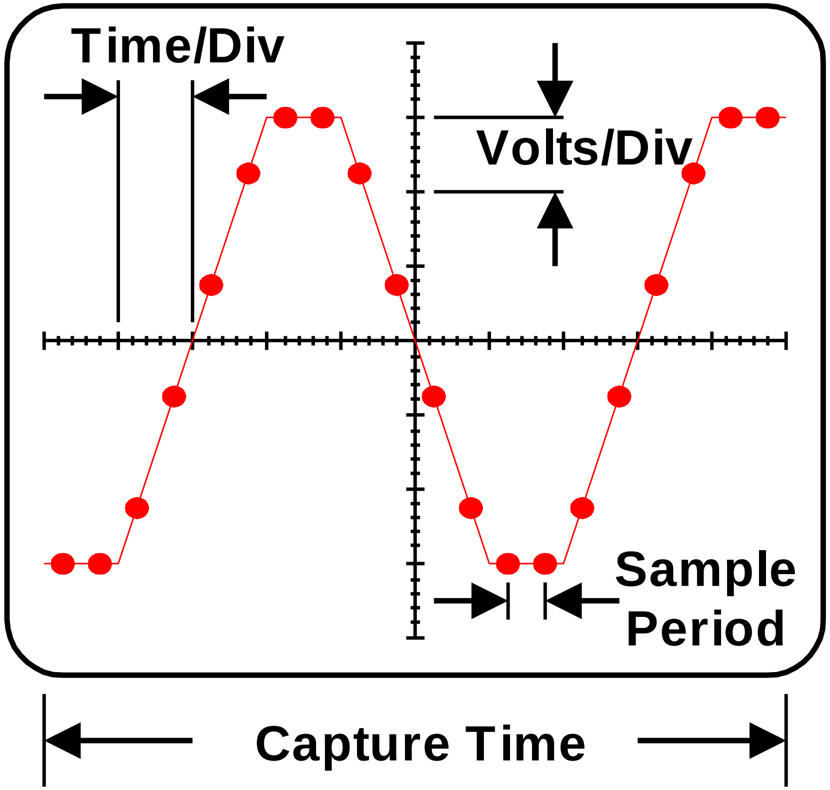
Short memory record: Correctly sample **part** of the data



Short memory record: **Incorrectly** sample all of the data



Relationship Between Sample Rate and Memory Depth



- Vertical range is 8 x [Volts/Div] ≈ 256 binary codes for 8-bit ADC
- Capture time = 10 x [Time/Div]
- Sample Rate = 1 / Sample Period = Memory Depth / Capture Time
- Memory Depth = Sample Rate x Capture Time
- Digital Bandwidth (Nyquist frequency) = Sample Rate / 2
- Lowest Frequency that can be characterized = 1 / Capture Time
- Ratio of highest to lowest observable frequency = Memory Depth / 2

Sample Rate = (Memory Depth) / (Capture Time)

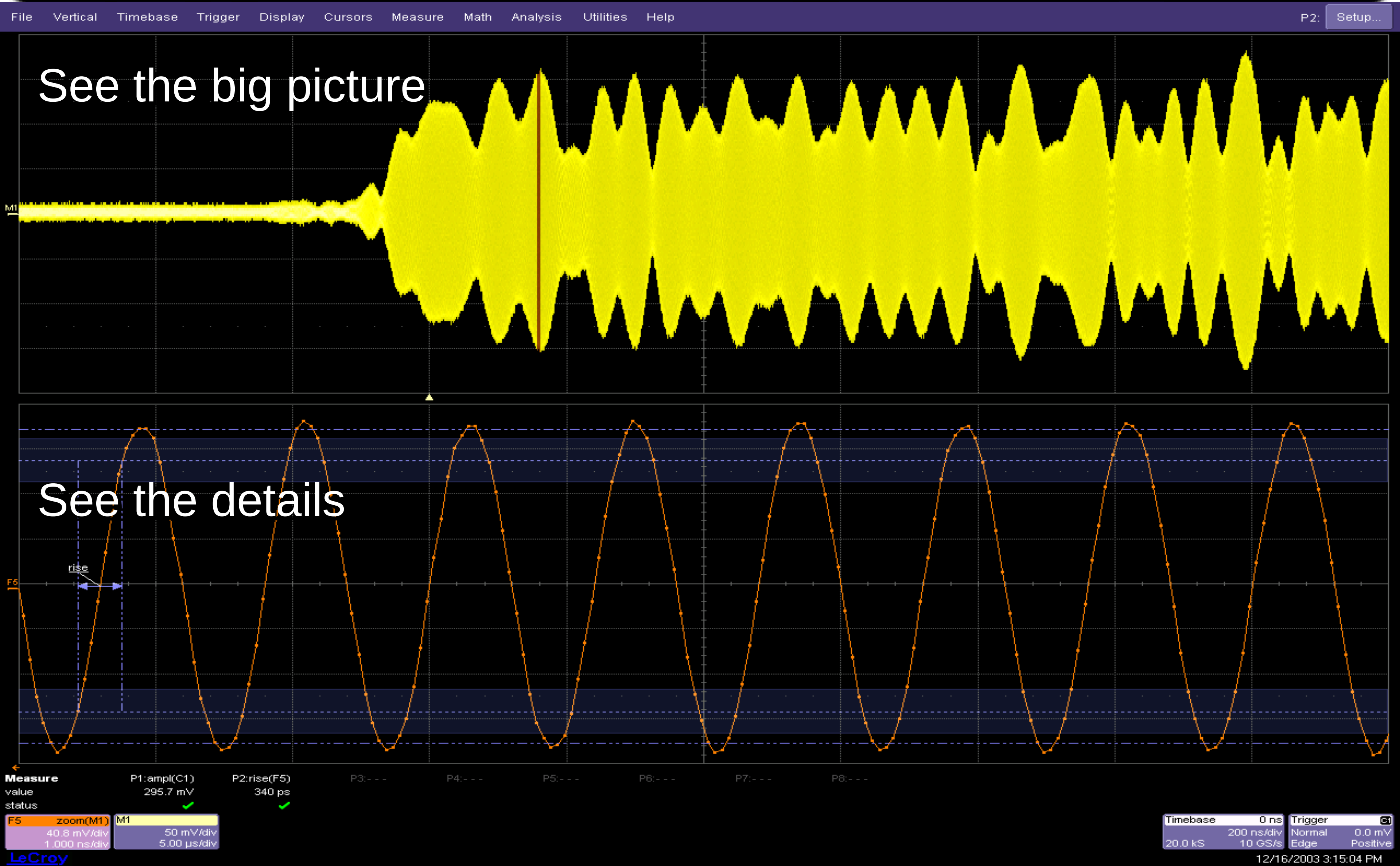
(where Capture Time = 10 * Time/Div)

Deep Memory Reduces Aliasing

Sample Rate = (Memory Depth) / (Capture Time)

- 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
- Deeper memory enables a longer capture time for a given sampling rate
- Deeper memory enables a higher sample rate and digital bandwidth for a given capture time
- A higher sampling rate reduces the risk of aliasing

Benefits of Long Memory:
See the Big Picture



See the big picture

See the details

Measure	P1:ampl(C1)	P2:rise(F5)	P3:- - -	P4:- - -	P5:- - -	P6:- - -	P7:- - -	P8:- - -
value	295.7 mV	340 ps						
status	✓	✓						

F5 zoom(M1) 40.8 mV/div 1.000 ns/div

M1 50 mV/div 5.00 µs/div

Timebase 0 ns 200 ns/div 20.0 kS 10 GS/s

Trigger C1 Normal 0.0 mV Edge Positive

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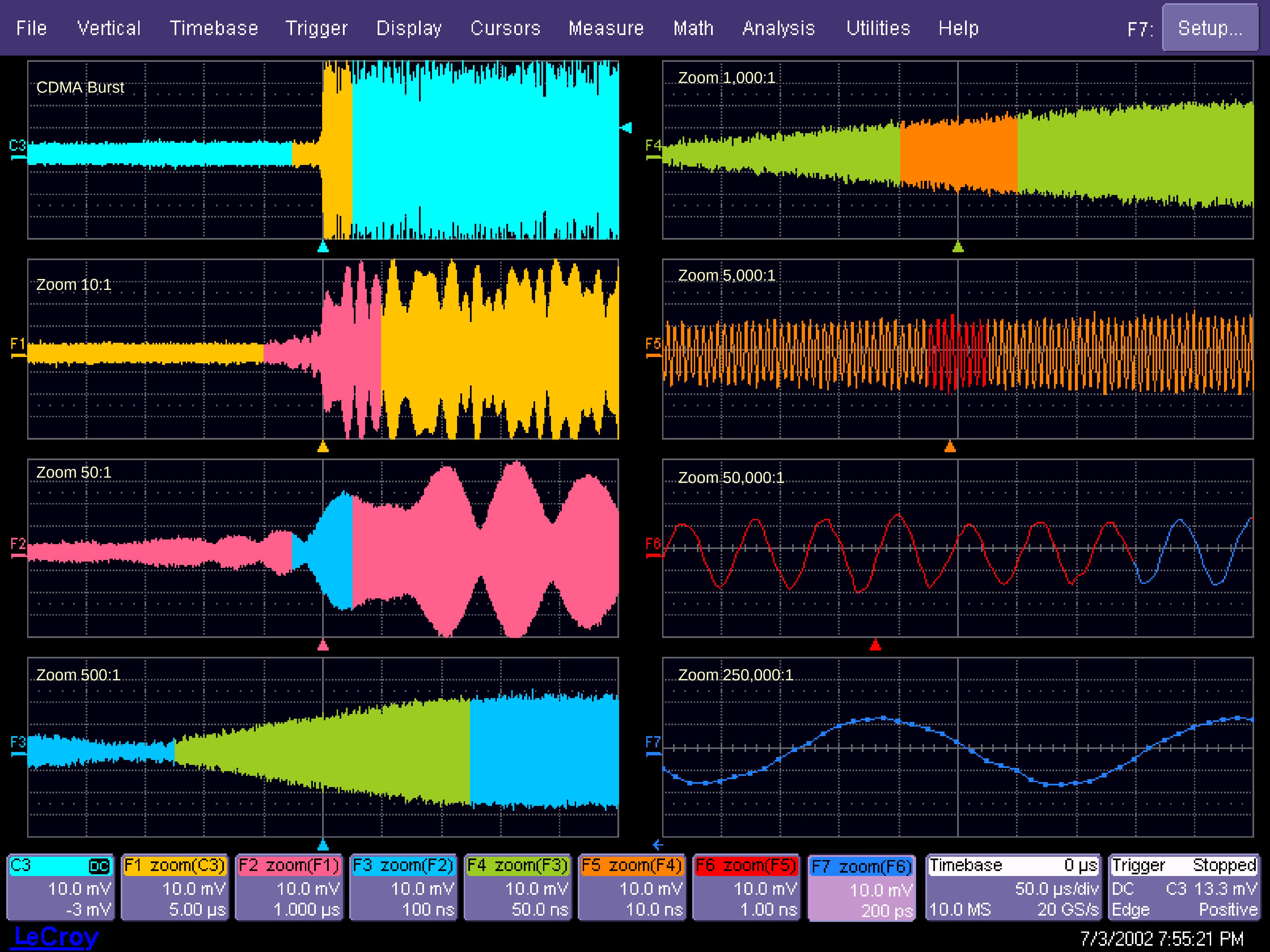

C3 DC 10.0 mV -3 mV

F1 zoom(C3) 10.0 mV 5.00 µs

F2 zoom(F1) 10.0 mV 1.000 µs

F3 zoom(F2) 10.0 mV 100 ns

F4 zoom(F3) 10.0 mV 50.0 ns

F5 zoom(F4) 10.0 mV 10.0 ns

F6 zoom(F5) 10.0 mV 1.00 ns

F7 zoom(F6) 10.0 mV 200 ps

Timebase 0 µs 50.0 µs/div 10.0 MS 20 GS/s

Trigger Stopped DC C3 13.3 mV Edge Positive

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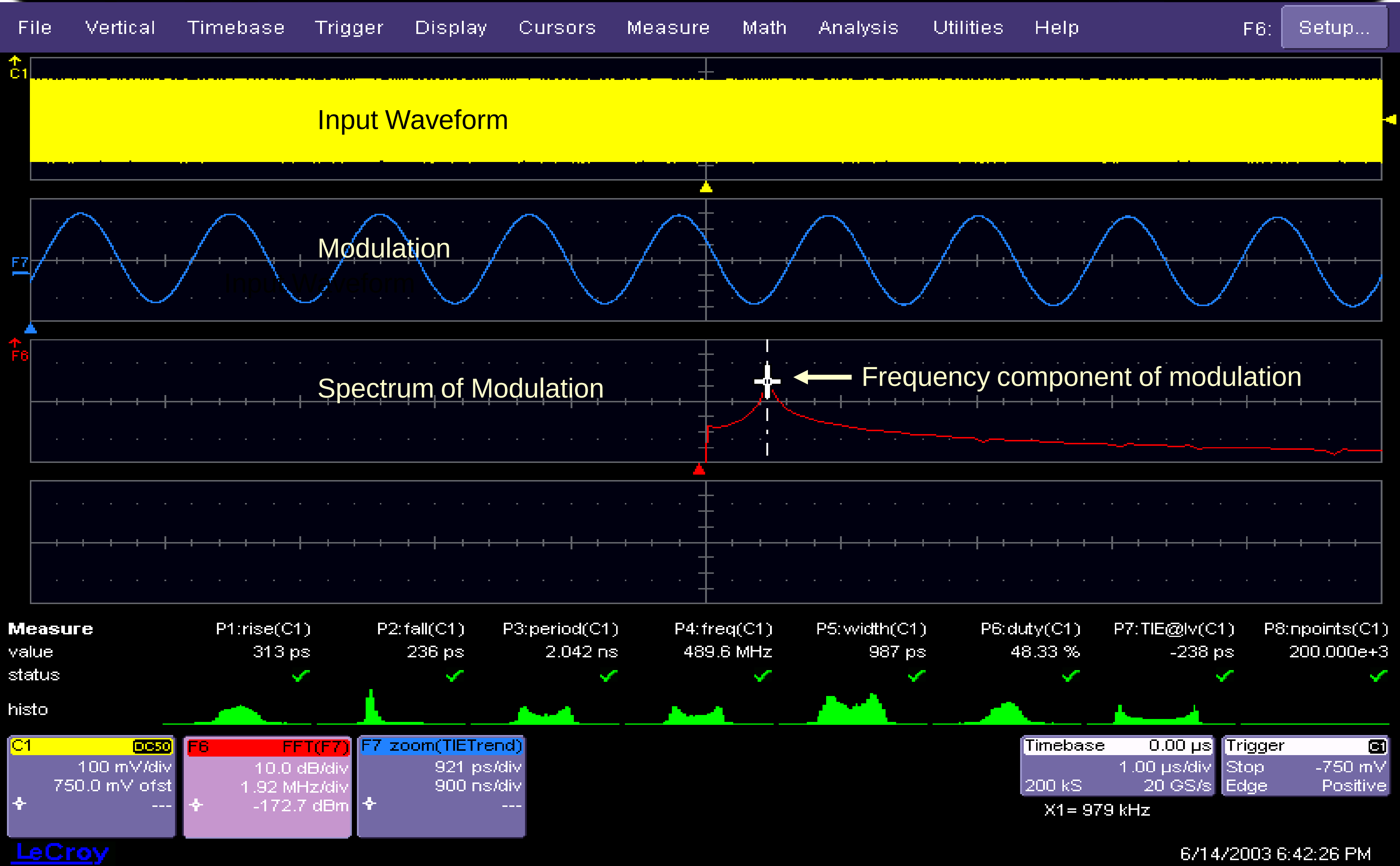
Benefits of Long Memory:

Detect Low Frequency Modulation



Input Waveform

Modulation

Spectrum of Modulation

Frequency component of modulation

Measure	P1:rise(C1)	P2:fall(C1)	P3:period(C1)	P4:freq(C1)	P5:width(C1)	P6:duty(C1)	P7:TIE@lv(C1)	P8:npoints(C1)
value	313 ps	236 ps	2.042 ns	489.6 MHz	987 ps	48.33 %	-238 ps	200.000e+3
status	✓	✓	✓	✓	✓	✓	✓	✓
histo								

C1 DC50
100 mV/div
750.0 mV ofst

F6 FFT(F7)
10.0 dB/div
1.92 MHz/div
-172.7 dBm

F7 zoom(TIETrend)
921 ps/div
900 ns/div

Timebase 0.00 µs
1.00 µs/div
200 kS 20 GS/s

Trigger C1
Stop -750 mV
Edge Positive

X1= 979 kHz

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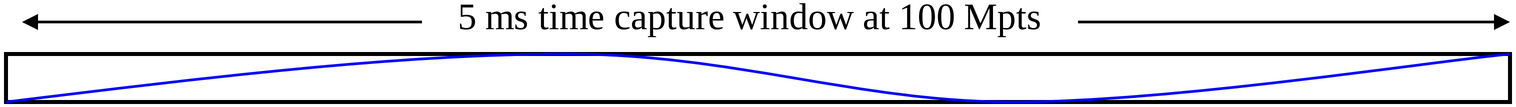
Relation Between Memory and Modulation Detection

100 Mpts



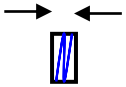
5 ms time capture window at 100 Mpts

With 100 Mpts sample memory, scope can detect modulation as low as **200 Hz**

---

1 Mpts

50 us time capture window at 1 Mpts



With 1 Mpts sample memory, scope can detect modulation as low as **20 kHz**

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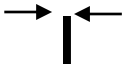
250 kpts

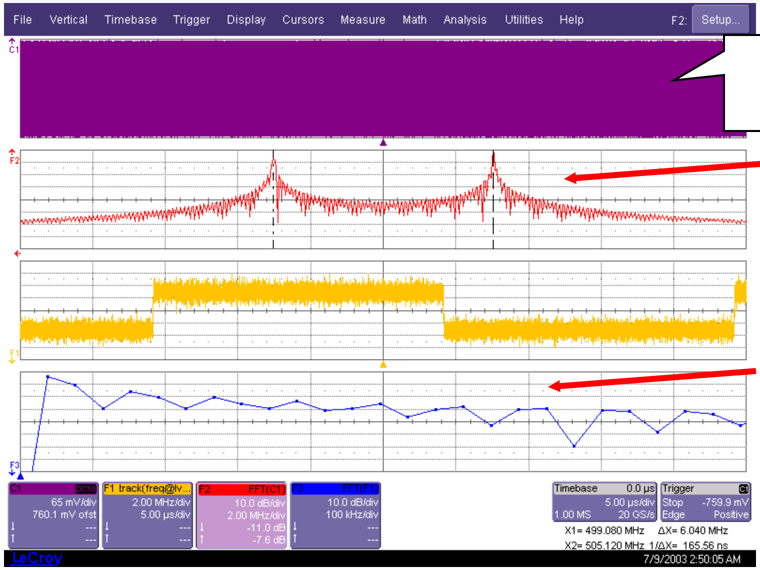
12.5 us time capture window at 250 kpts



With 250 kpts sample memory, scope can detect modulation as low as **80 kHz**

Benefits of Long Memory:

Deeper Memory Produces Better FFT Resolution

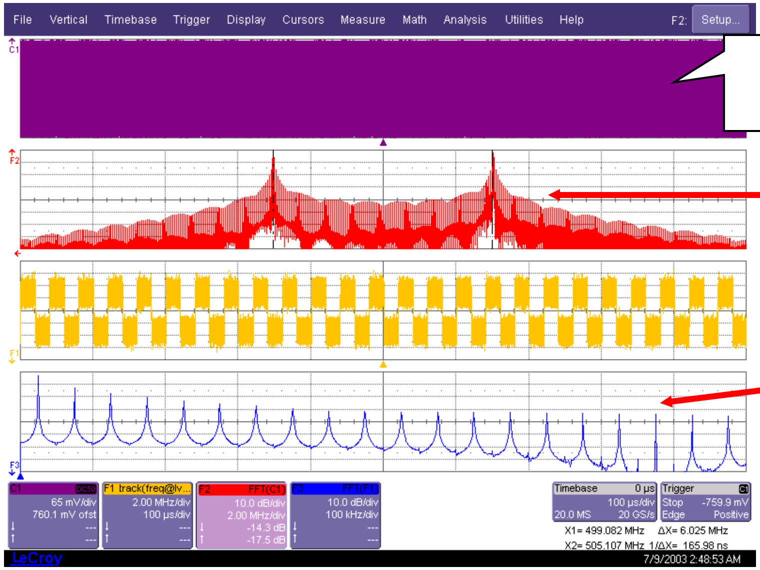


C1 DC50 65 mV/div 760.1 mV ofst
F1 track(freq@lv... 2.00 MHz/div 5.00 µs/div
F2 FFT(C1) 10.0 dB/div 2.00 MHz/div ↓ -11.0 dB ↑ -7.6 dB
F3 FFT(F1) 10.0 dB/div 100 kHz/div
Timebase 0.0 µs 5.00 µs/div 1.00 MS 20 GS/s
Trigger C1 Stop -759.9 mV Edge Positive
X1= 499.080 MHz ΔX= 6.040 MHz
X2= 505.120 MHz 1/ΔX= 165.56 ns
7/9/2003 2:50:05 AM

Capture Time
= 50 us (1 Mpts)

Cannot tell anything about modulation

Peaks cannot be distinguished



C1 DC50 65 mV/div 760.1 mV ofst
F1 track(freq@lv... 2.00 MHz/div 100 µs/div
F2 FFT(C1) 10.0 dB/div 2.00 MHz/div ↓ -14.3 dB ↑ -17.5 dB
F3 FFT(F1) 10.0 dB/div 100 kHz/div
Timebase 0 µs 100 µs/div 20.0 MS 20 GS/s
Trigger C1 Stop -759.9 mV Edge Positive
X1= 499.082 MHz ΔX= 6.025 MHz
X2= 505.107 MHz 1/ΔX= 165.98 ns
7/9/2003 2:48:53 AM

Capture Time
= 1 ms (20 Mpts)

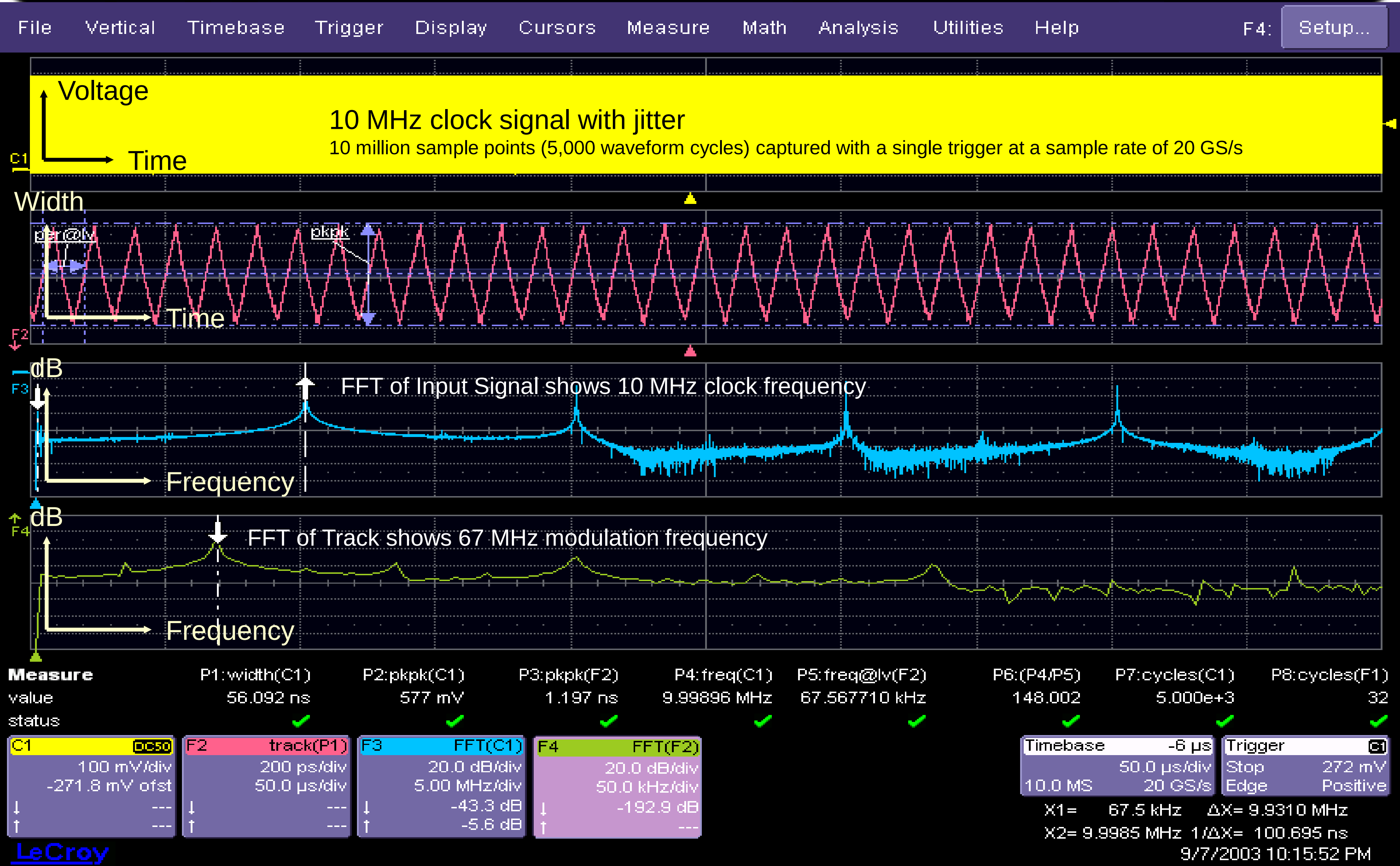
Scalloped shape indicates pulse modulation

Peaks are clearly resolved

- Deep memory increases frequency resolution and improves signal to noise ratio
- Note the refined detail in the FFTs calculated from 20 Mpt records

Benefits of Long Memory:

Identify Jitter Source



Voltage

Time

10 MHz clock signal with jitter

10 million sample points (5,000 waveform cycles) captured with a single trigger at a sample rate of 20 GS/s

Width

Time

dB

FFT of Input Signal shows 10 MHz clock frequency

Frequency

dB

FFT of Track shows 67 MHz modulation frequency

Frequency

Measure	P1:width(C1)	P2:pkpk(C1)	P3:pkpk(F2)	P4:freq(C1)	P5:freq@lv(F2)	P6:(P4/P5)	P7:cycles(C1)	P8:cycles(F1)
value	56.092 ns	577 mV	1.197 ns	9.99896 MHz	67.567710 kHz	148.002	5.000e+3	32
status	✓	✓	✓	✓	✓	✓	✓	✓

C1 DC50
100 mV/div
-271.8 mV ofst
↓ ---
↑ ---

F2 track(P1)
200 ps/div
50.0 µs/div
↓ ---
↑ ---

F3 FFT(C1)
20.0 dB/div
5.00 MHz/div
↓ -43.3 dB
↑ -5.6 dB

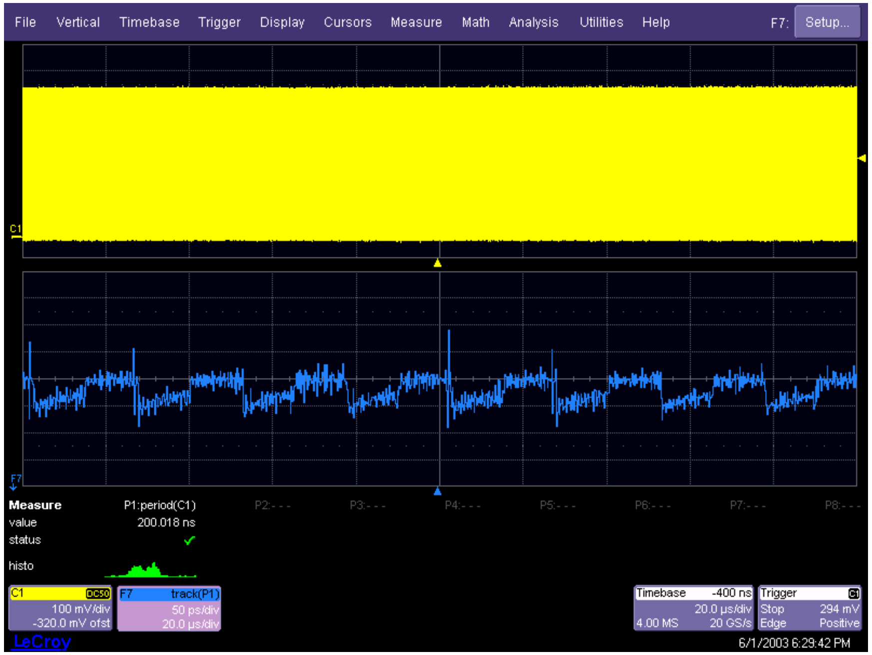
F4 FFT(F2)
20.0 dB/div
50.0 kHz/div
↓ -192.9 dB
↑ ---

Timebase -6 µs
50.0 µs/div
10.0 MS 20 GS/s

Trigger C1
Stop 272 mV
Edge Positive

X1= 67.5 kHz ΔX= 9.9310 MHz
X2= 9.9985 MHz 1/ΔX= 100.695 ns
9/7/2003 10:15:52 PM

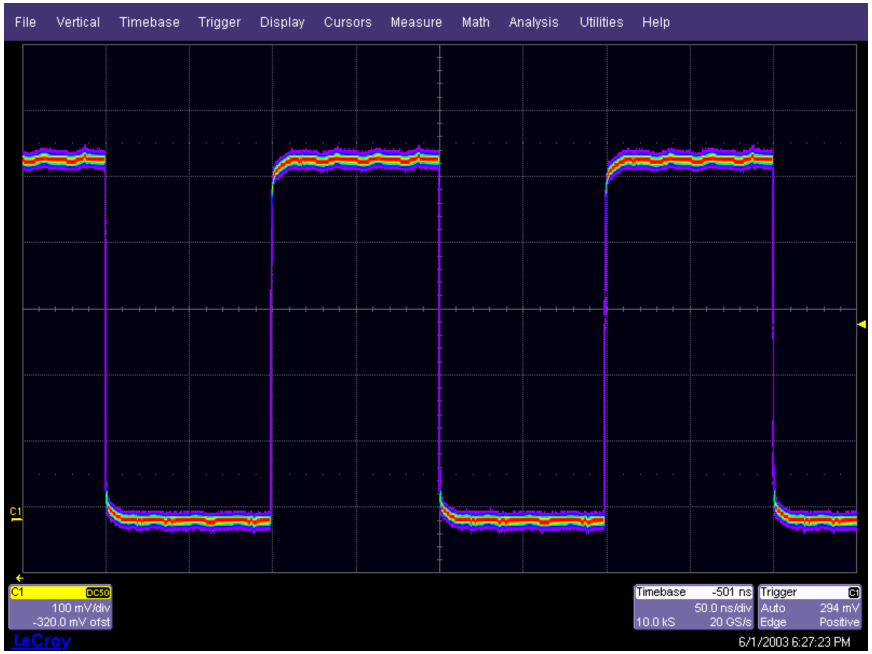
Persistence Mode Does Not Detect This Modulation



Measure P1:period(C1) P2:- - - P3:- - - P4:- - - P5:- - - P6:- - - P7:- - - P8:- - -
value 200.018 ns
status ✓
histo

C1 DC50 100 mV/div -320.0 mV ofst
F7 track(P1) 50 ps/div 20.0 µs/div
Timebase -400 ns 20.0 µs/div 4.00 MS 20 GS/s
Trigger C1 Stop 294 mV Edge Positive
6/1/2003 6:29:42 PM

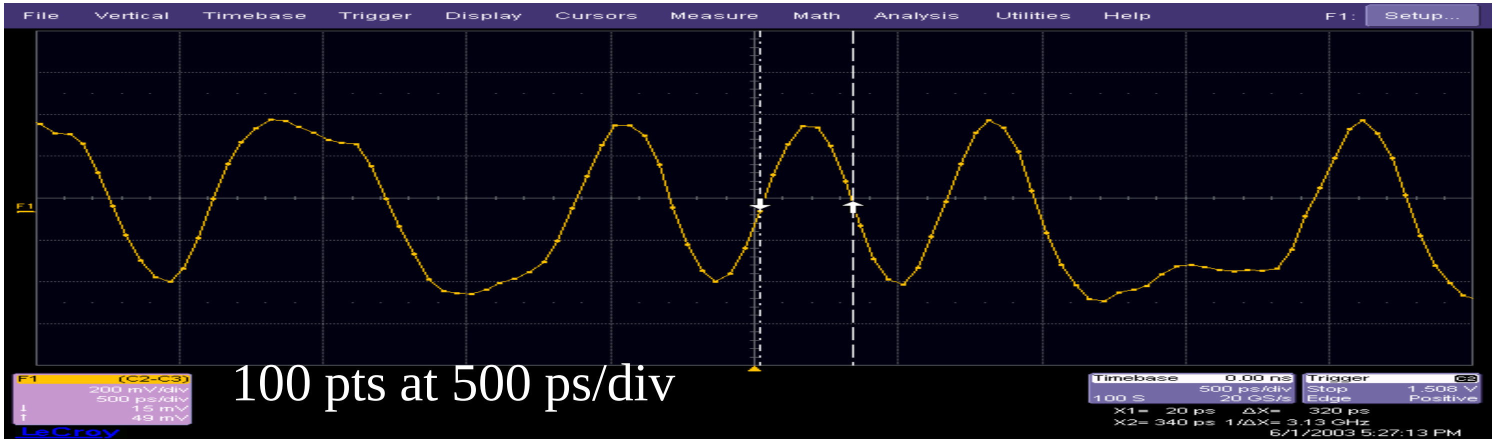
Modulation detected using deep memory record



C1 DC50 100 mV/div -320.0 mV ofst
Timebase -501 ns 50.0 ns/div 10.0 kS 20 GS/s
Trigger C1 Auto 294 mV Edge Positive
6/1/2003 6:27:23 PM

Modulation is invisible using persistence mode

Oscilloscope Display and Memory



100 pts at 500 ps/div

$$\left(\frac{100\,Mpts}{acquisition}\right)\bullet\left(\frac{8''\,display}{100\,pts}\right)\bullet\left(\frac{1\;foot}{12''}\right)\bullet\left(\frac{1\,mile}{5280\;feet}\right)=\frac{126.26\;display\;miles}{acquisition}$$

100 Mpts of memory is equivalent to 126 miles of oscilloscope display