Agilent Webcast Template 2.0 Instructions

Agilent Technologies

Introduction to Jitter and Jitter Measurements

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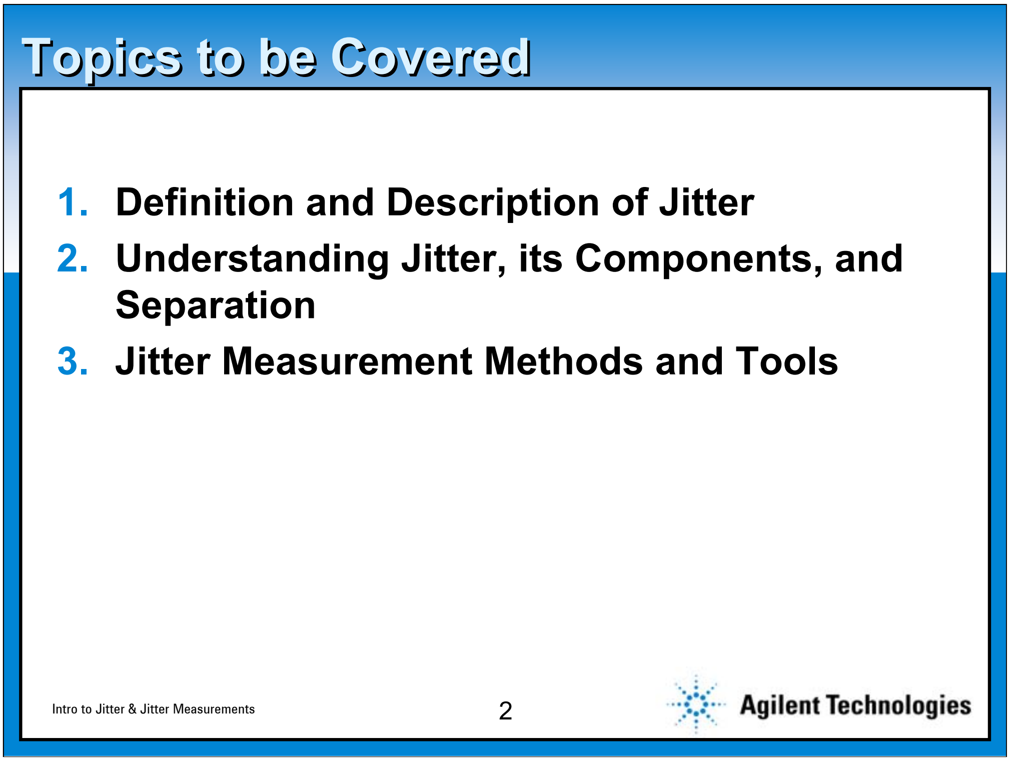
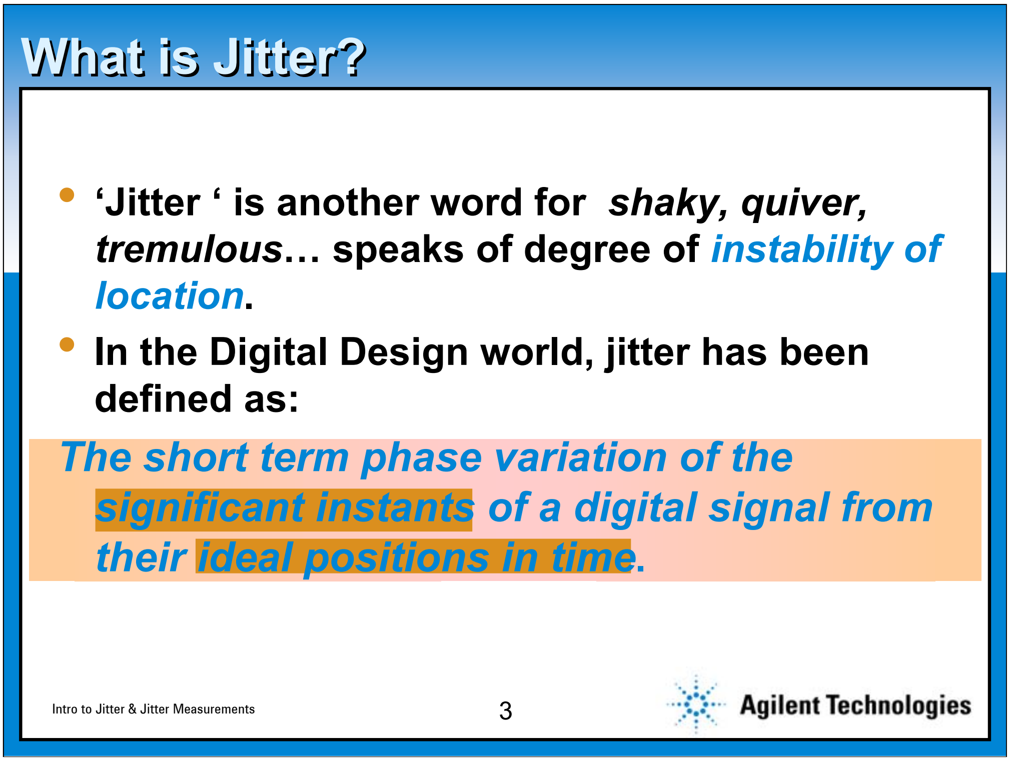
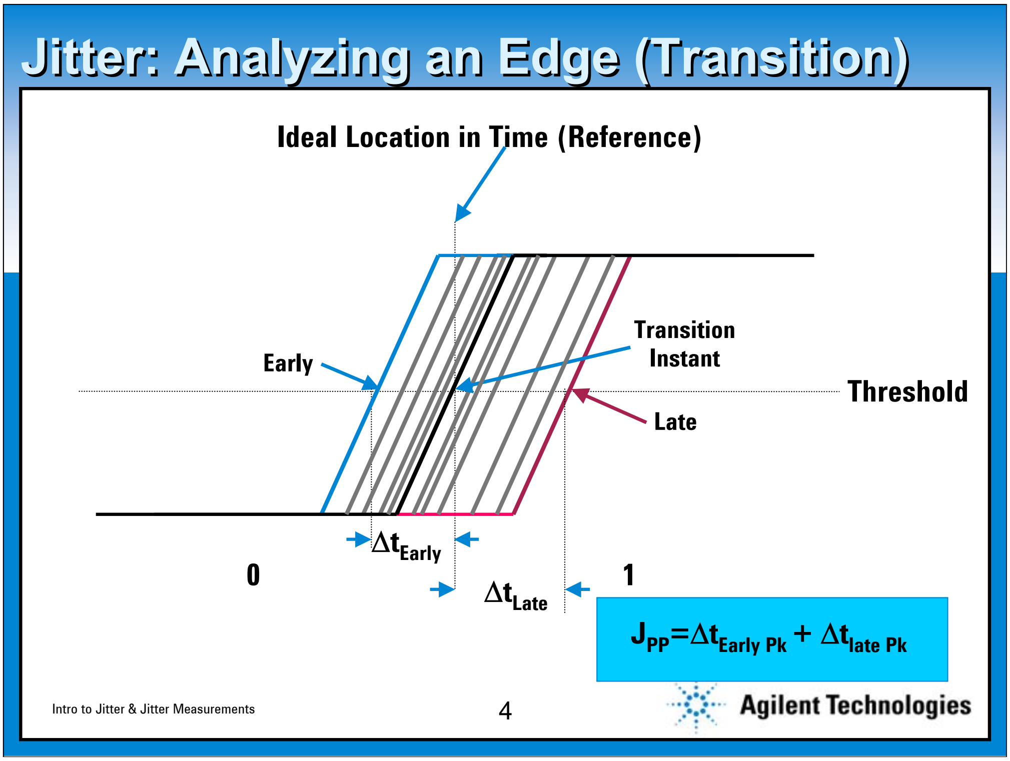


Today we will be covering a lot of ground in the jitter space. The goal is to put you a knowledge level where insight into circuit or system performance can be converted to actionable knowledge. We will start with the basics, the definition and descriptions and then dig into understanding the components of jitter—how they add or contribute to overall Total Jitter and how they can be identified through several of the views that are possible with todays tools. And speaking of tools, we will discuss many of these, their attributes, their advantages and disadvantages.

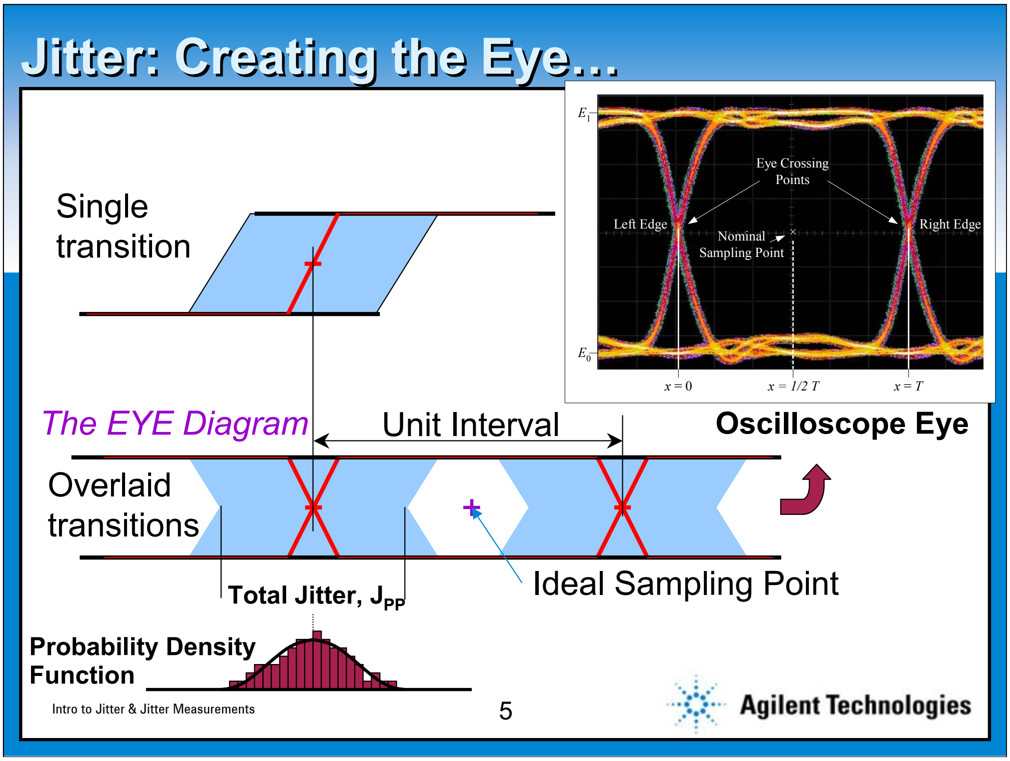


Jitter is a word folks associate with instability…. Like the jitters on a golf course, coffee jitters etc. The second definition is the electrical engineers definition of jitter.   Lets see what it means….



This graphic assumes we have the magic ability to look at every 0 to 1 trajectory in a signal. We must understand that in order to measure jitter we must have an expectation of timing location of a trajectory… this can be accomplished several ways. So using this magic ability we watch the edges and we note that some come early some come late. After a sufficient time we can say that there was a 'latest one' and an 'earliest one'… These two values (added absolutely) constitute Peak to peak jitter.

So why do we care? Well what happens if an edge comes way too early or way too late?….



Again we do the slide build thing…

We start with a pictorial of the rising edge… and we show a blue area denoting some sort of probabilistic cloud of edges. But the rising edges arent the only story so lets include falling edges as well. When we do get this idealized eye where we have two crossing points where the red x's are and the clouds about them. If the shaded region isn't too big we will have a space where no trajectory goes and the center of this will be where the idealized sampling point is for lowest possible error.

We note that as before the extremes about a crossing point (at a specific threshold hopefully related to the receiver circuit) is the Jitter peak to peak.

If we kept track of every edge's advance and delay value and binned them and counted the number in each bin we would build a histogram as depicted here. The histogram is a very important view of jitter.

Finally, a real world eye is shown which is very open, but you will note has some over shoot to it.

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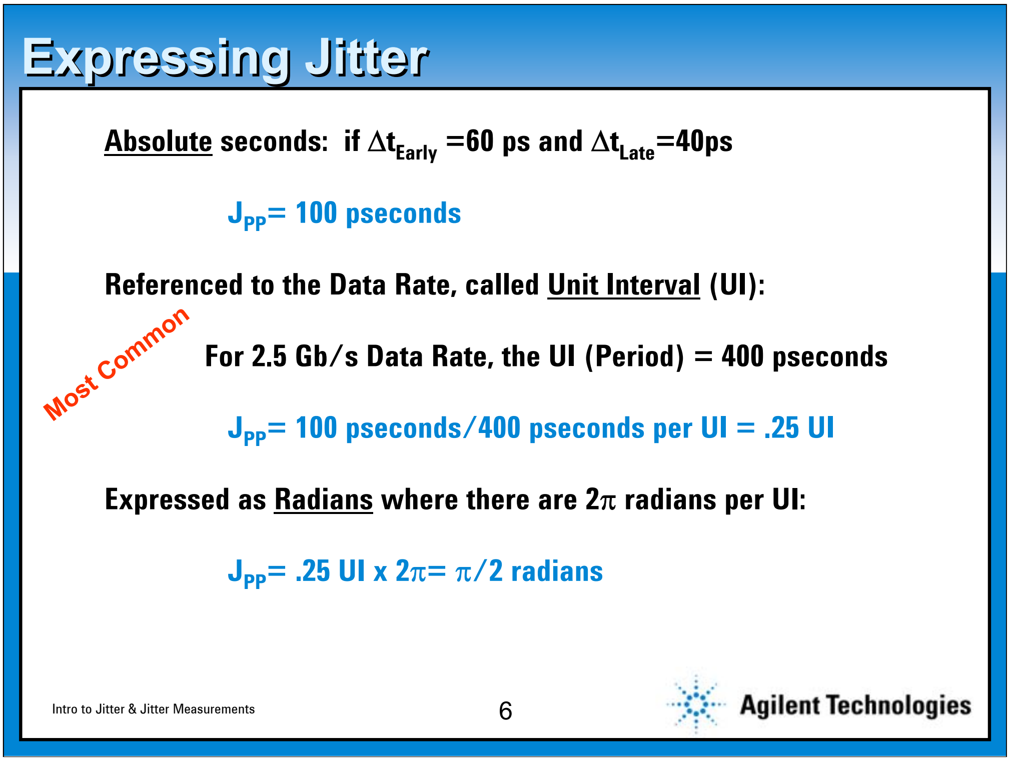
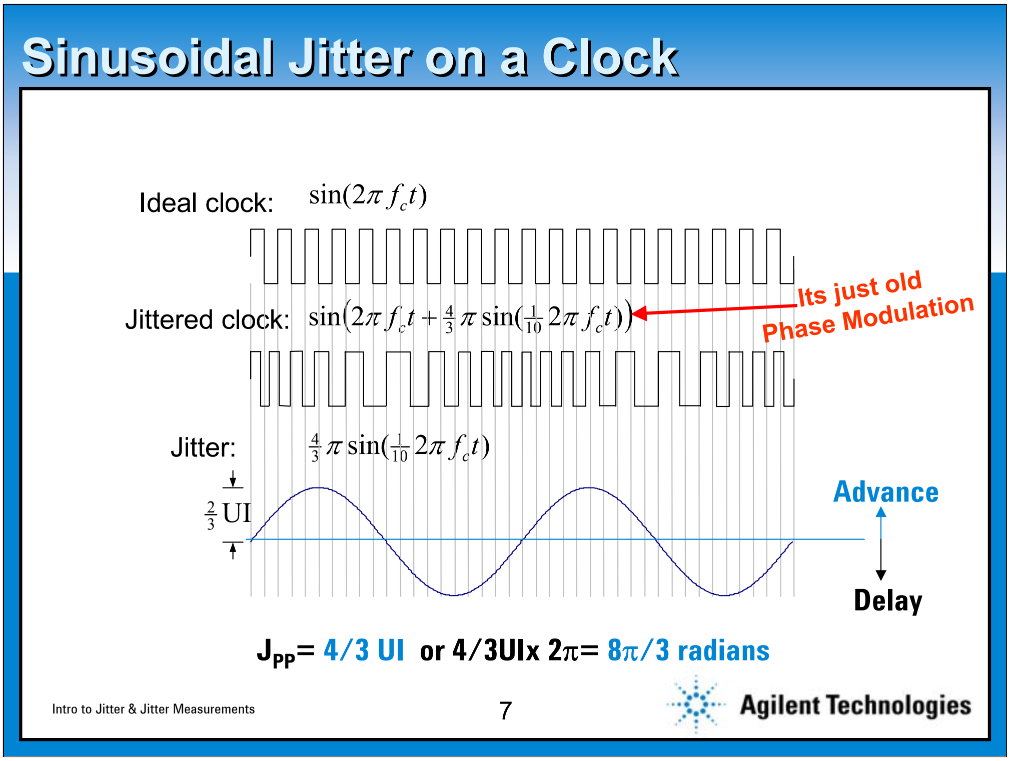
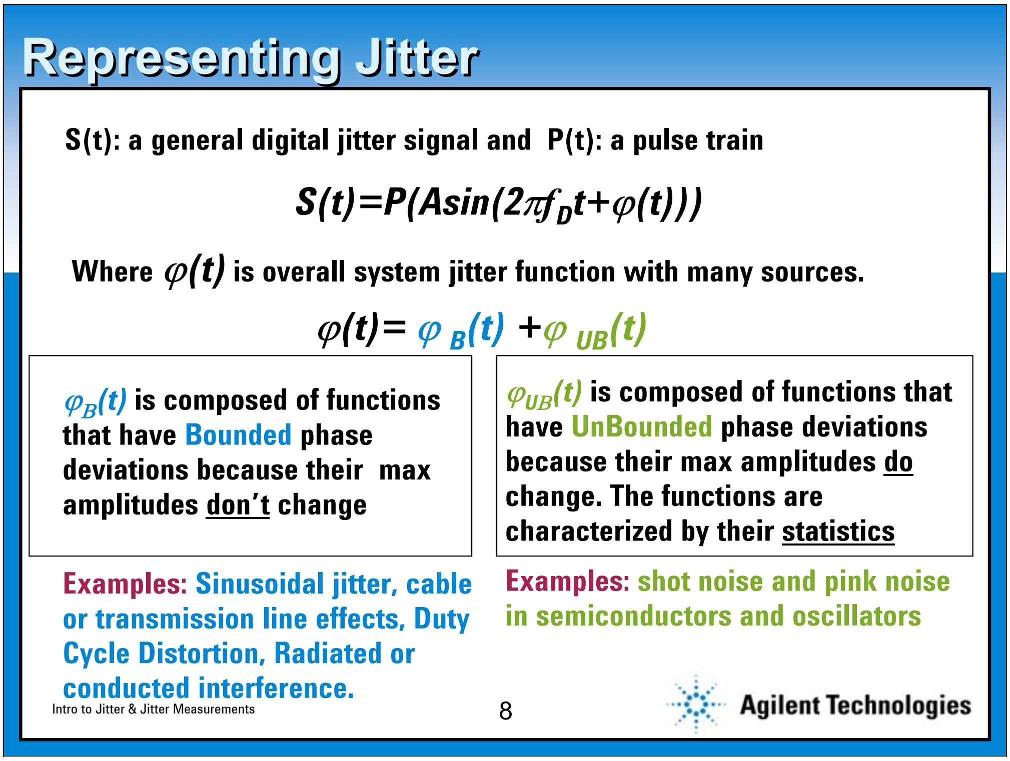


Here we express jitter as Total Jitter in absolute seconds, unit interval and as radians. We can do the same with Random Jitter as well. In this case we express jitter in RMS terms. So we might say we have 10 ps random jitter sigma or 10/400 = .025 UI RMS.

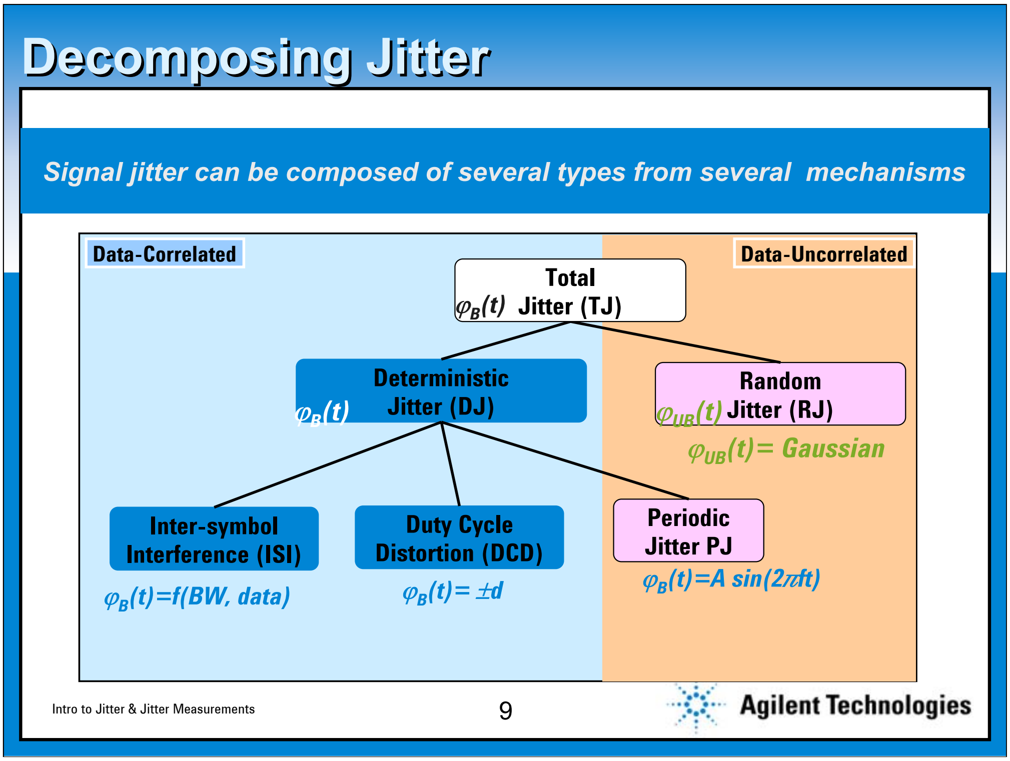


Take a clock signal and jitter it with a sinewave signal of 1/10 the frequency and you note (middle waveform) that we have phase modulated the clock. We have jittered the clock with a nice waveform, a sinusoid. This is for example only as rarely is the jitter signal just a sinusoid



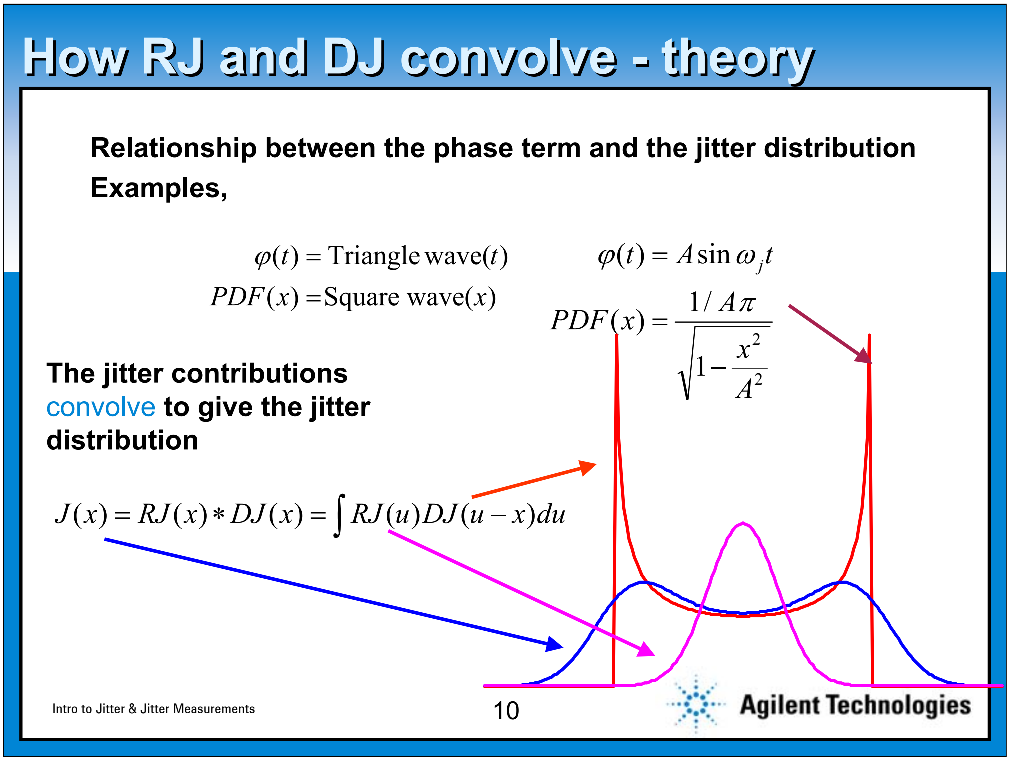
Here we generalize the jittered digital signal but now we use an arbitrary function phi(t) instead of the sinusoid. We will take this one step further by asserting that this phi(t) is really a composite function of several jitter adding functions that can be classified into bounded and unbounded sources. The bounded functions which if considered repetitive on some basis will never exceed a given amount… for instance the sinusoid we showed earlier will never get beyond 2/3 UI peak. Unbounded functions can grow arbitrarily large… it's a function of how long you want to wait---they are not predictable and we can only know them by their statistics.

These are the two major classes of jitter: Bounded, or Deterministic and Unbounded, or Random Jitter



This graphic further dissects jitter--- here the first level of taxonomy shows that Total Jitter is composed of Deterministic (DJ) and Random (RJ). DJ can be further decomposed into that which is Data Correlated or Data Uncorrelated. For Data uncorrelated, sinusoidal jitter, such as you might find from a power supply regulator field is a type of periodic jitter. For Data correlated we have intersymbol interference and Duty cycle distortion. ISI is the degree that previous symbols or bits as they go through the system impulse response affect subsequent bits. Duty Cycle Distortion, DCD, refers to asymmetry in on/off times or degree of offset in receive circuit threshold.

It should be noted that there is another jitter type which is not shown which is uncorrelated and that is bounded uncorrelated jitter, BUJ, which is not periodic but may be present in systems nonetheless because of infrequent events– this type changes many assumptions in analysis as it defies stationarity



A natural question is how do these sources of jitter add? This graphic illustrates that they add by convolution. Observe that Independent DJ sources will essentially add in a peak to peak manner whilst independent RJ sources will add in RMS fashion.

Note that the Sinusoidal source has a U-shaped distribution which is because at the extremes of the sinusoid it is changing VERY slowly—so it spends most of the time there.

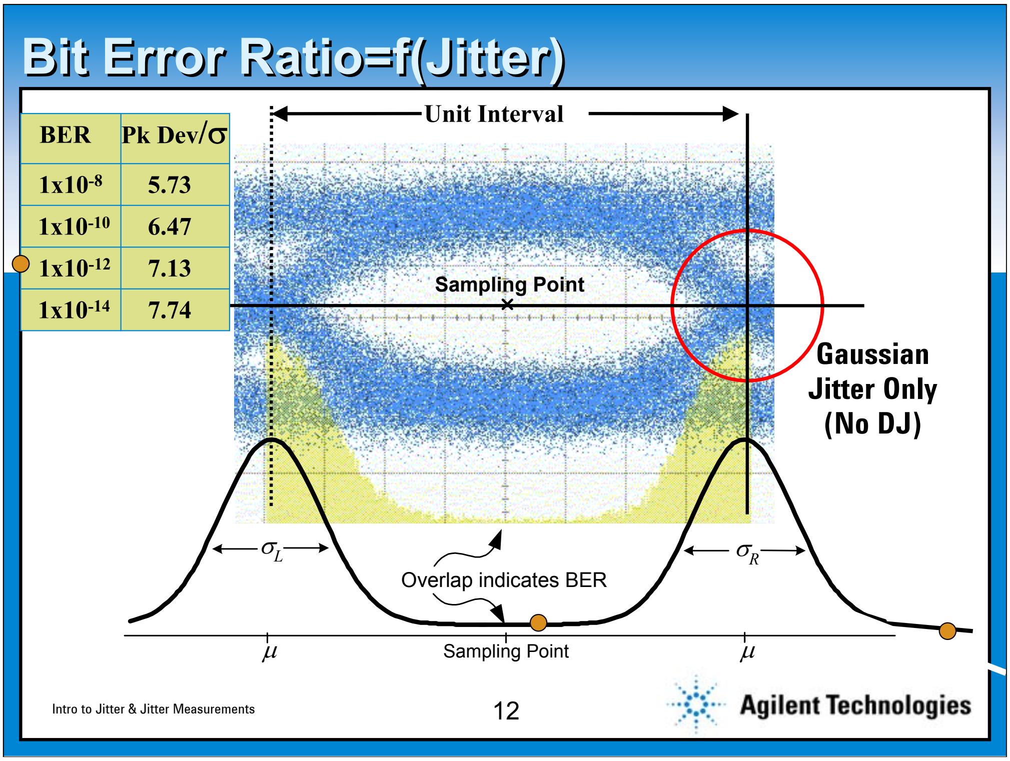
The Problem…

- Only Bit Error Rate Testers can determine J_{PP} directly.
  But:
  Measurement times are LONG– perhaps Hours for a 2.5 Gbs signal using standard Bathtub Software.
- But there is a way to estimate J_{PP}….
  If we can separate RJ and DJ, AND
  Measure both accurately…

So we mentioned that we are interested in Total Jitter, TJ, by considering the earliest and latest arriving edges. But with random jitter we know we have to wait some time before we will get a representative sample of edges. So the question is: How long do we have to wait? Or better yet the question really is "How many bits do we need to evaluate?"

Well for 95% confidence we need to see about 4x the number of bits than our target Bit Error Ratio with NO errors. So with no errors at a desired $1x10^{-12}$ Bit Error ratio we need to look at ~$4x10^{12}$! At 1Gbs this is 4000 seconds! At 2.5Gbs this is 1600 seconds which is almost half an hour. For any other point below this, say at 10^{-13} BER you will wait 5 hours!

So it's the RJ that's causing this problem… if we could separate it out and estimate it accurately we could shorten this time considerably.



So lets go with an jittered signal with RJ only! About each crossing point we will get histograms as shown. So, remember we asked earlier, 'What happens if the late edge is way too late?" and " what if the early edge is way too early?" Using the right crossing point distribution we can answer the 'early' question. If the sampling point is in the exact middle and the edge occurs right then or slightly before then we have an error. So now we know where the problem is, but what is the probability that the problem occurs? Well if we take that distribution and integrate it from negative infinity to minus .5UI that area so calculated better be less than the target BER, say 10^{-12} BER. We can look up Gaussian tables for this and if we do find that this point occurs around 7 sigma from the mean of the distribution. So if this 7 sigma point occurs to the right of the sampling point we can support something better than 10^{-12} Bit Error Ratio.

The next thing we observe is that the same logic can be applied to the left crossing point. And noting that both of these distributions are theoretically the same we quickly can rationalize that the peak to peak jitter for a gaussian jittered signal that can support 10^{-12} BER is 14*sigma and that 1 UI>14 sigma

Total Jitter Estimate

For a BER = $10^{-12} \rightarrow J_{PP}^{RJ} = 14 \times \sigma$ …*7 for each tail*

Then $J_{PP}^{RJ} \equiv n \times \sigma$ or $= n \times J_{rms}^{RJ}$

The Total Jitter (TJ), J_{PP}, for a 10^{-12} BER **with** Deterministic Jitter is estimated:

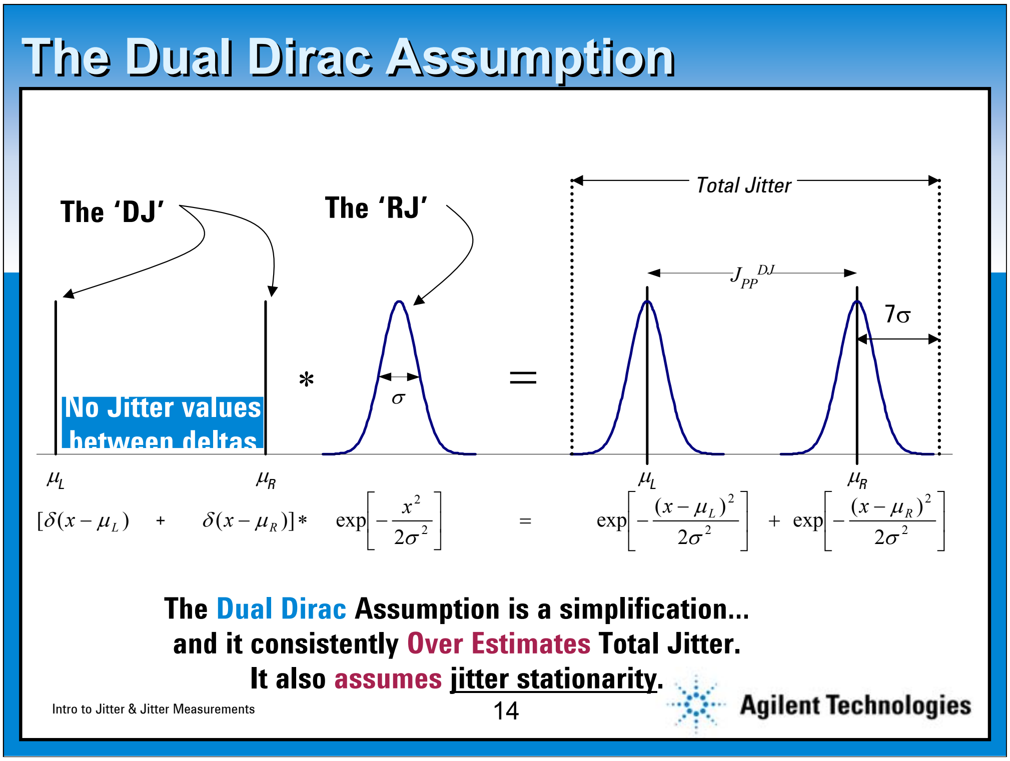
$$J^{TJ} = n \times J_{rms}^{RJ} + J_{PP}^{DJ}$$
$$= 14 \times \sigma + J_{PP}^{DJ}$$

This assumes that the Gaussian RJ PDF 'appends' to the DJ PDF

This is called the Dual Dirac Assumption

This slide combines the previous result with deterministic jitter to give us an overall expression that combines DJ and RJ to yield Total Jitter or TJ. This is shown in the blue square.

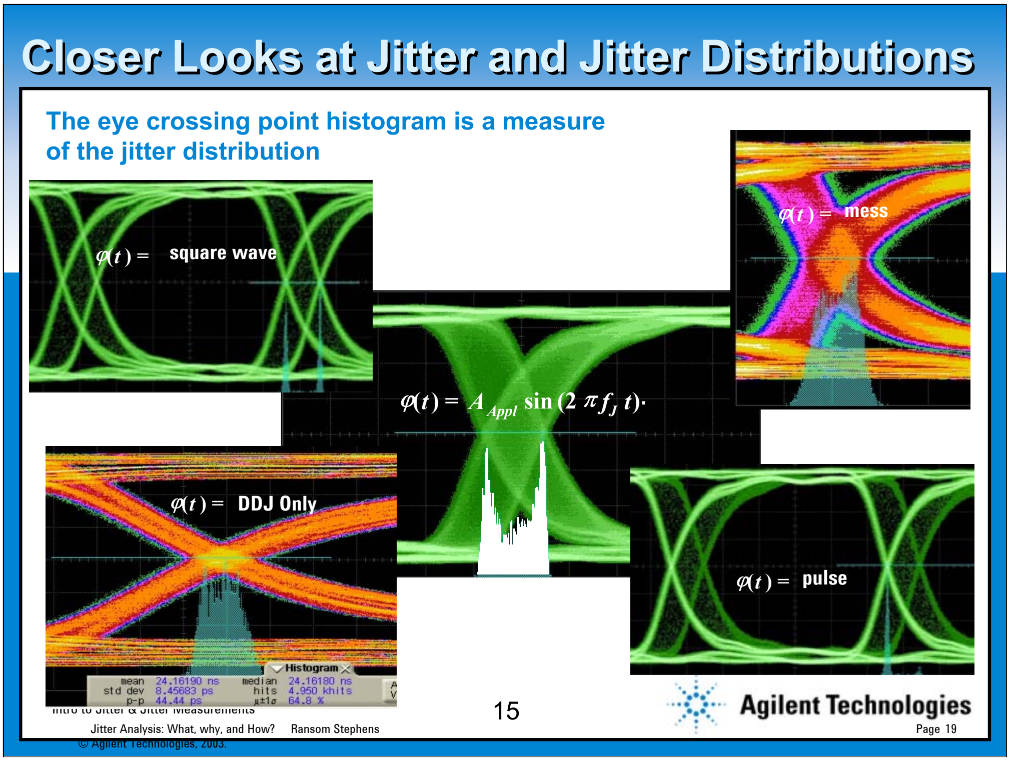
This assumes that all DJ is at its extreme values which is conservative– it therefore OVERESTIMATES jitter because depending on the DJ distribution, most of the time it is NOT at its extremes. This assumption is called the dual dirac assumption



A brief interlude on the Dual Dirac…

The right hand picture shows the convolution of RJ with DJ that is all located its extremes.

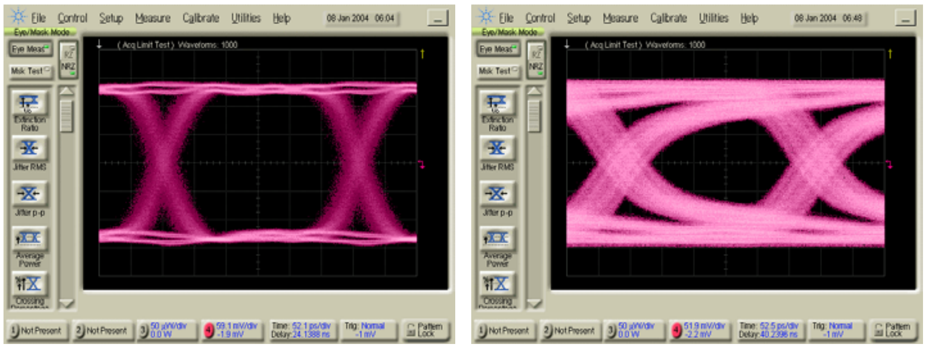
Jitter stationarity is ALWAYS assumed right now. It is difficult otherwise to analyze jitter. One way to justify this is to consider nonstationarity a system interference issue that is a debug concern.



Here are some looks at jitter….

Top left hand is a square wave jitter---both trajectories about each crossing point are equally intense. Bottom right in contrast is a 5% duty cycle square wave so the histogram shows a 19x difference in height. Center: sinusoidal jitter (note u-shaped distribution). Bottom left is ISI or DDJ---have wide crossing point caused by many trajectories. Top right is a whole shmear of jitter.

Which Eye Has Worse Jitter?

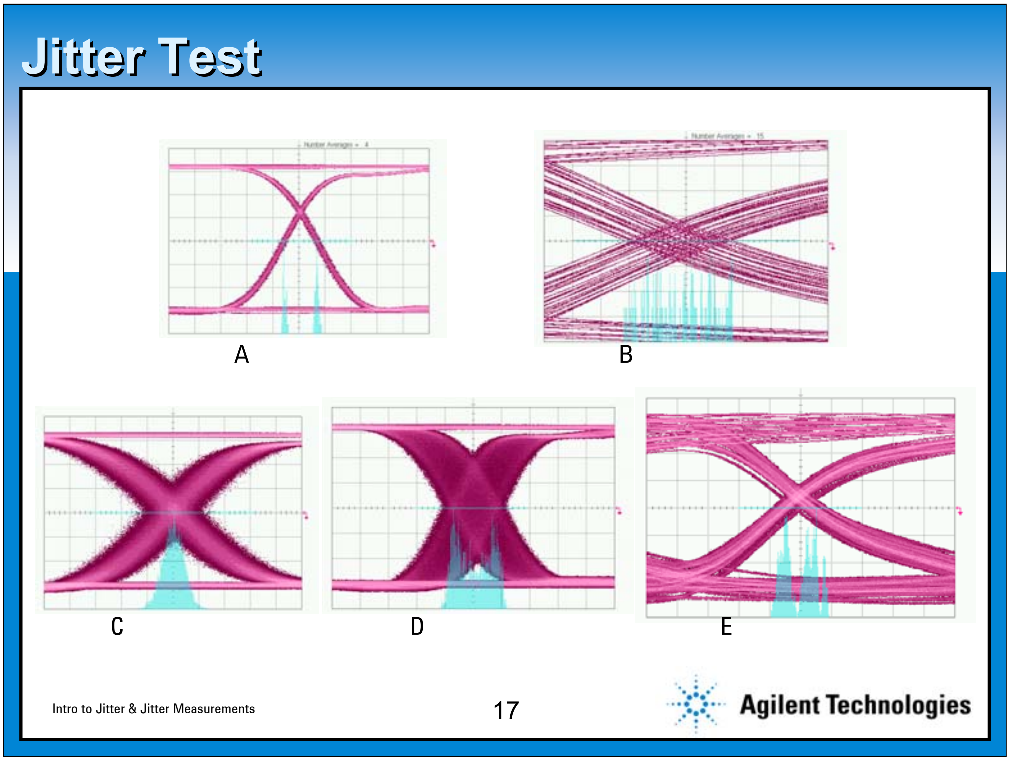


A B

You can't know unless you measure the Total Jitter or measure the jitter components!

We answer this later in the presentation…

But spend some time on audience impressions of both



A=duty cycle distortion---note double delta… but it is not the same as double delta caused by square wave jitter shown 2 slides ago

B= ISI---note the many trajectories…. The striation is a dead ringer

C=RJ---looks pretty gaussian

D=Sinusoidal (note the u-shaped distribution)

E= Striation AND High crossing point =>ISI and DCD

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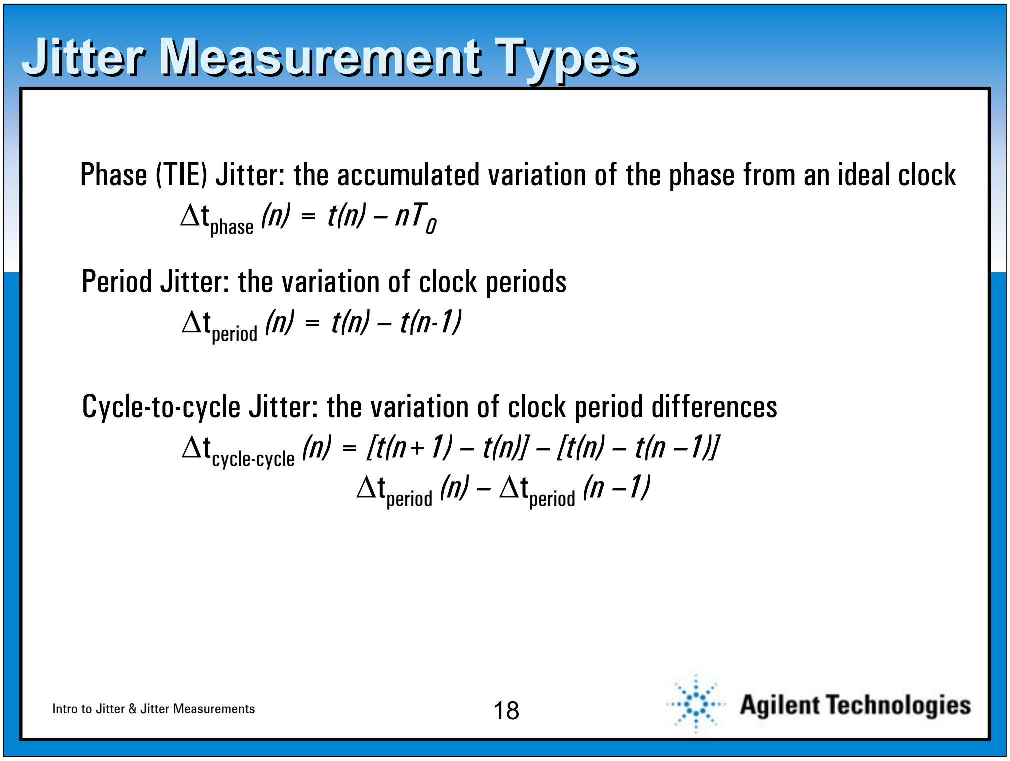
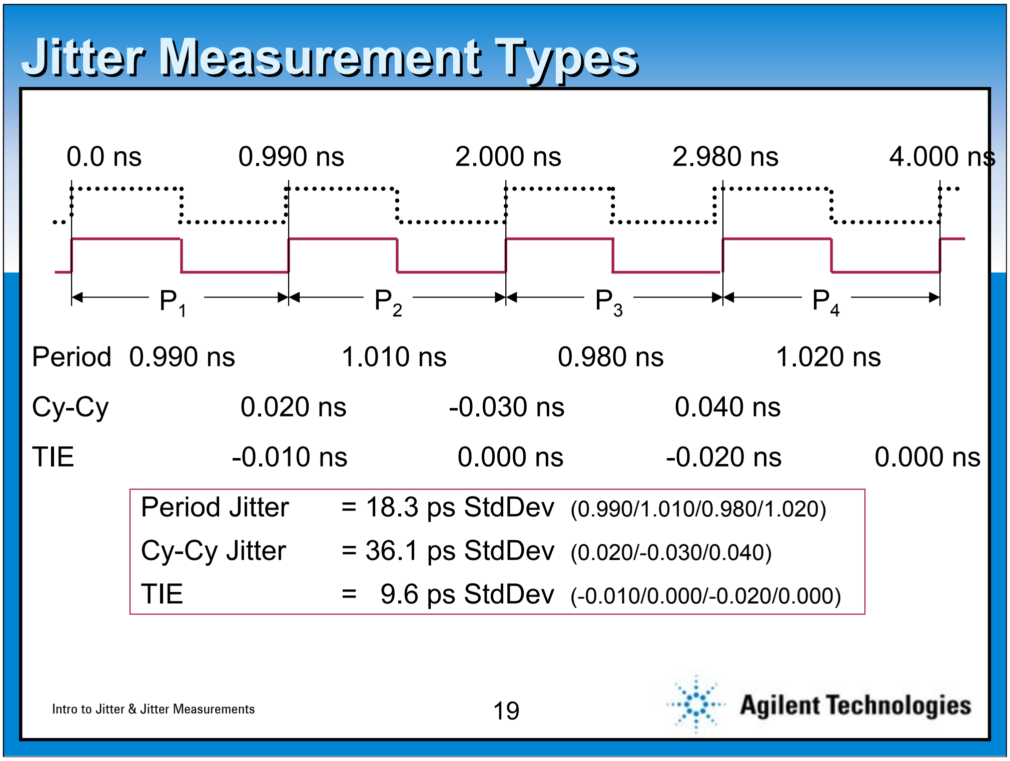


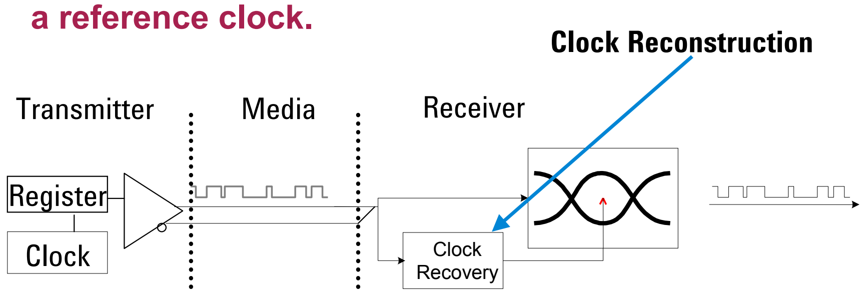
A recent interaction with a customer revealed that they had a component with a jitter specification from a third party but the two parties could not agree on the result. It turns the part was specified as total jitter but no indication was made on how this was measured. There really is no good assumption to make as many default to TIE while others are interest in period jitter or cycle to cycle. It is a good idea to understand the methodology customers are using. When specific standards are brought up there should be no ambiguity. SATA: Cycle to Cycle; FibreChannel: TIE; etc.



This example points out the difference between the various methods. For period jitter, the average value is the nominal period and std deviation is the jitter sigma. For the cycle to cycle, the average value indicates long term period error and should be about 0 for short term jitter and longish records. Time Interval Error is the difference from an extracted (or explicit) clock on a cycle to cycle basis…low frequency variations will be followed according to a PLL formula that the receiver circuits will implement.

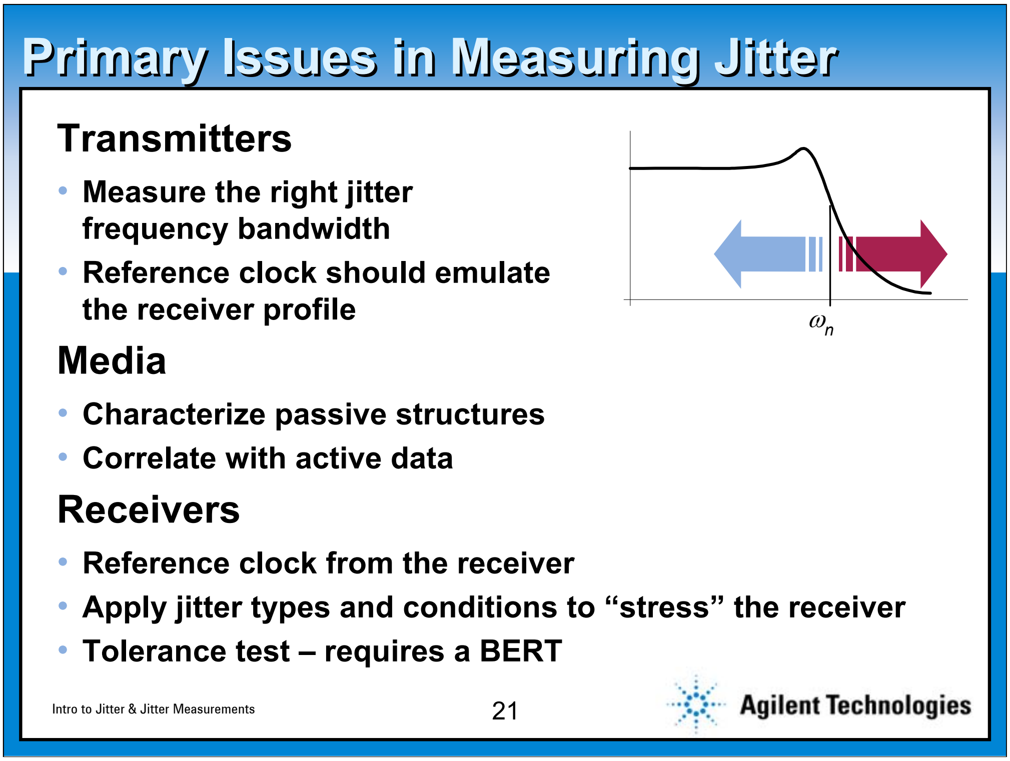
Jitter and Serial Data Technologies (Enterprise)

- All jitter analysis is a comparison of a test clock and a reference clock.



- Infiniband
- S-ATA
- PCI-Express
- CEI-6,11
- GbE
- Fibrechannel

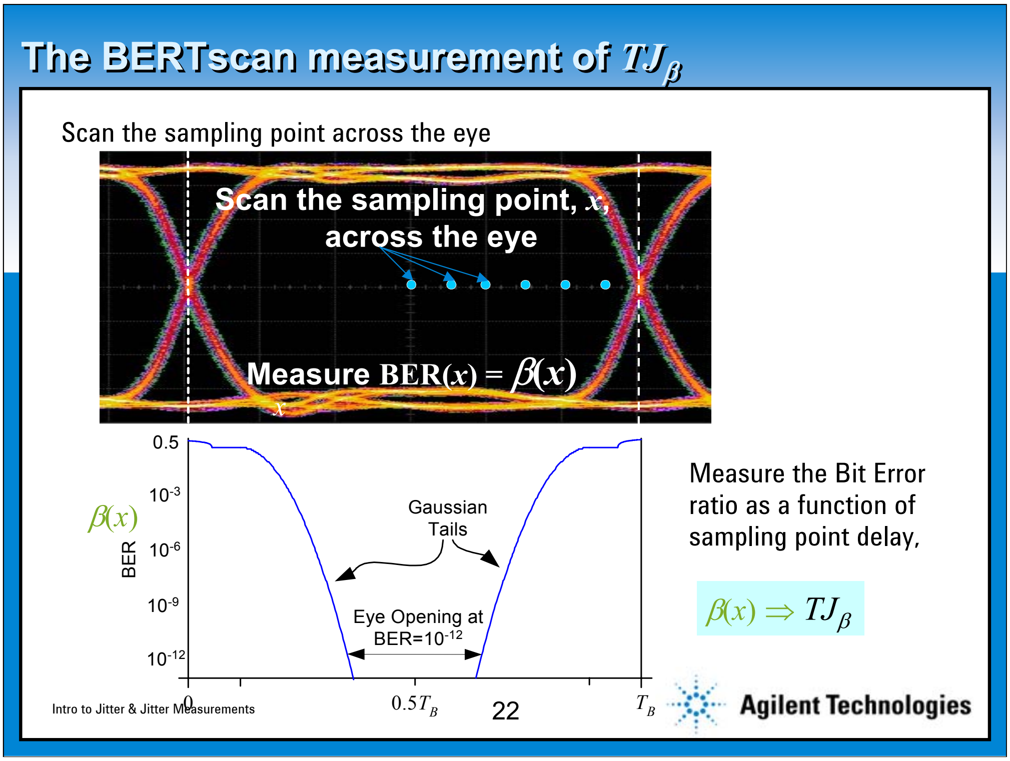
The main understanding for jitter is that it is a comparison to a reference clock. In serial communications, that reference clock is from a clock recovery circuit that is generated from the incoming data. There are applications where there is an explicit clock that may be regenerated by Phase Locked Loops and is only approximately phase coherent with the clocked data. Skew and compensation for it is important in these systems, but generally the same kind of concerns still exist.



This slide points out the three segments that concern customers in the jitter space. For transmitter measurement we need to point out that proper set up is required for correlation with receivers.

Folks designing integrated circuits are also interested in the receiver performance…. Not only its level sensitivity but how well it handles jittered signals in so-called ‘stressed’ signals.

Lastly, for those doing board integration such as backplane or system designers, understanding how the transport of data through the media affects the robustness of the link is key. This can be done without actual digital data being analyzed as it is a function of the impulse response of the path. If the impulse response has significant energy approximately one bit interval or more away then the path will affect the total jitter because of intersymbol interference



The BERTScan measurement is also called the BathTub measurement as the cross-section of a bathtub has the same precipitous decline. The idea is to dynamically change the sampling point (which normally is ideally placed in the middle) throughout the whole UI and to measure the number of failing and passing bits at each location until a statistically valid sample has been measured. It is clear that if we sample too close to either crossing point that we will have a greater likelihood of error and as we move toward the center it drops off. Note that the vertical axis is in powers of 10 in Bit Error Ratio so it is indeed falling off rapidly.

The key to understanding this is that the total jitter is determined by what BER is chosen and the opening at that point. Total Jitter is the Unit Interval minus the width of the bathtub on the left side (to the opening) minus the width of the bathtub on the right side.

Jitter Separation

Measuring J_{PP} directly is time consuming…to estimate it quickly we need to obtain J_{PP}^{RJ} (σ), and J_{PP}^{DJ}, (DJ). There are a number of ways to do this.

- **A.** Curve fit a Jitter PDF to a Gaussian (find the effective σ and mean)
- **B.** Curve fit an integrated Jitter PDF (erfc(x)) to obtain a parabolic function in σ.
- **C.** Determine spectrum of the Time Interval Error, remove spurs, and use noise floor to estimate σ. Use spur levels to estimate DJ.
- **D.** Determine Spectrum of non-data-correlated components. Use noise floor to estimate σ. Determine best fit to RJ/PJ PDF

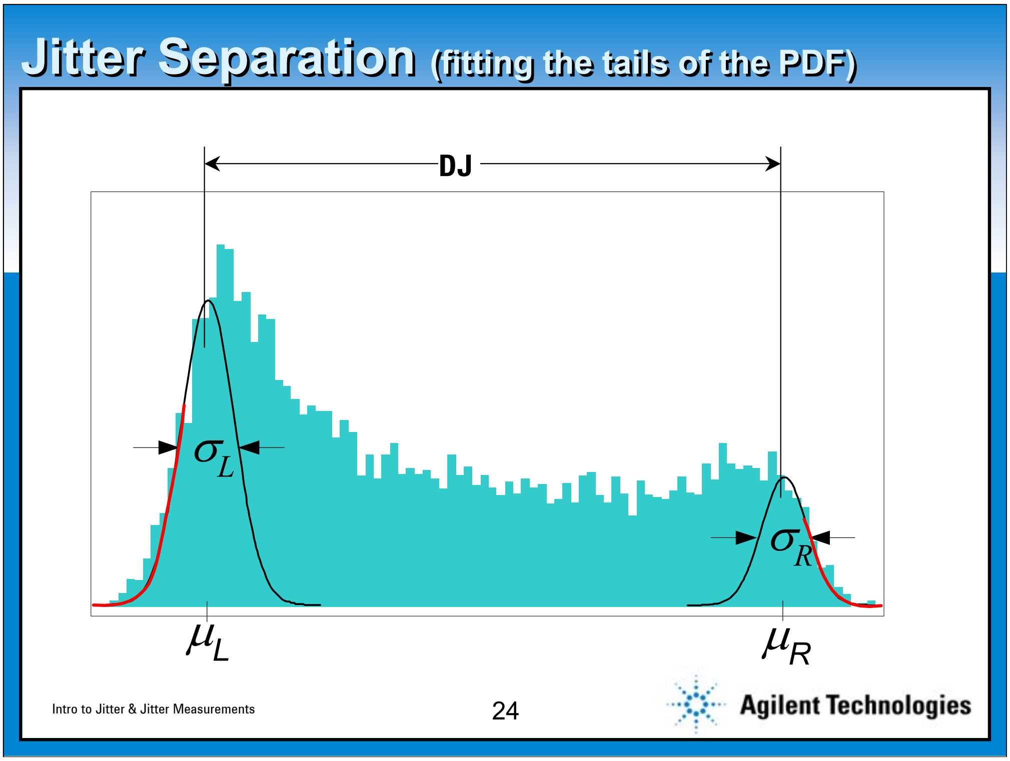
This is self explanatory however it might be useful to know that:

A= Wavecrest method

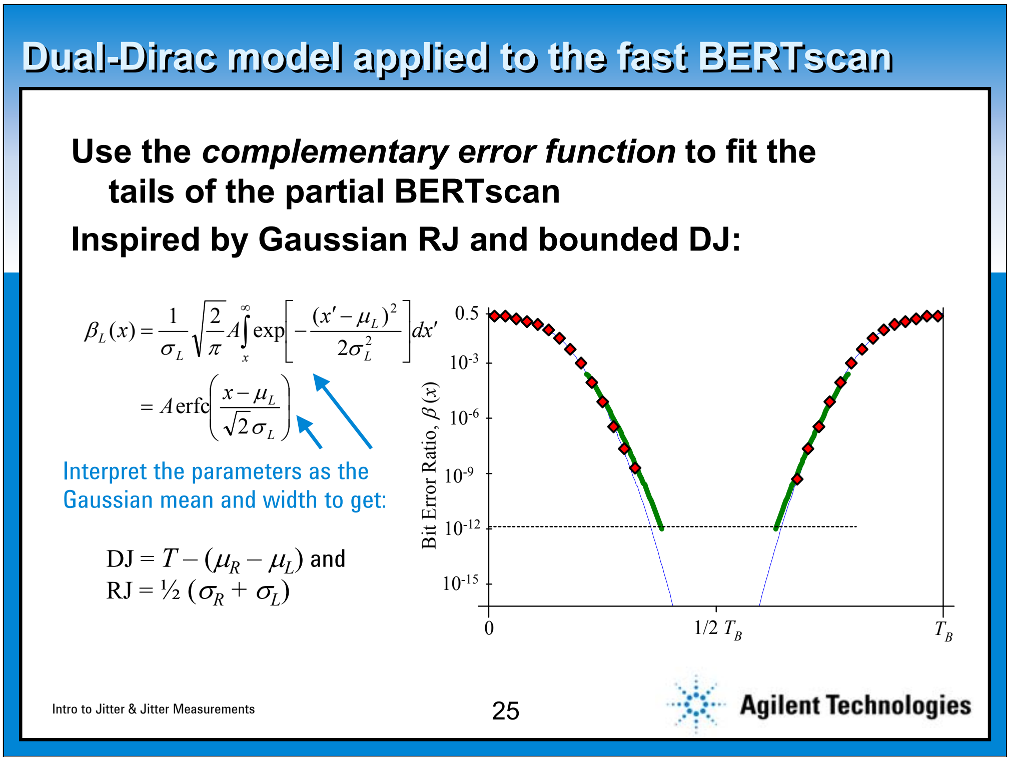
B=LeCroy, BERT extrapolation and one of the M1 methods

C=Tek Jit3

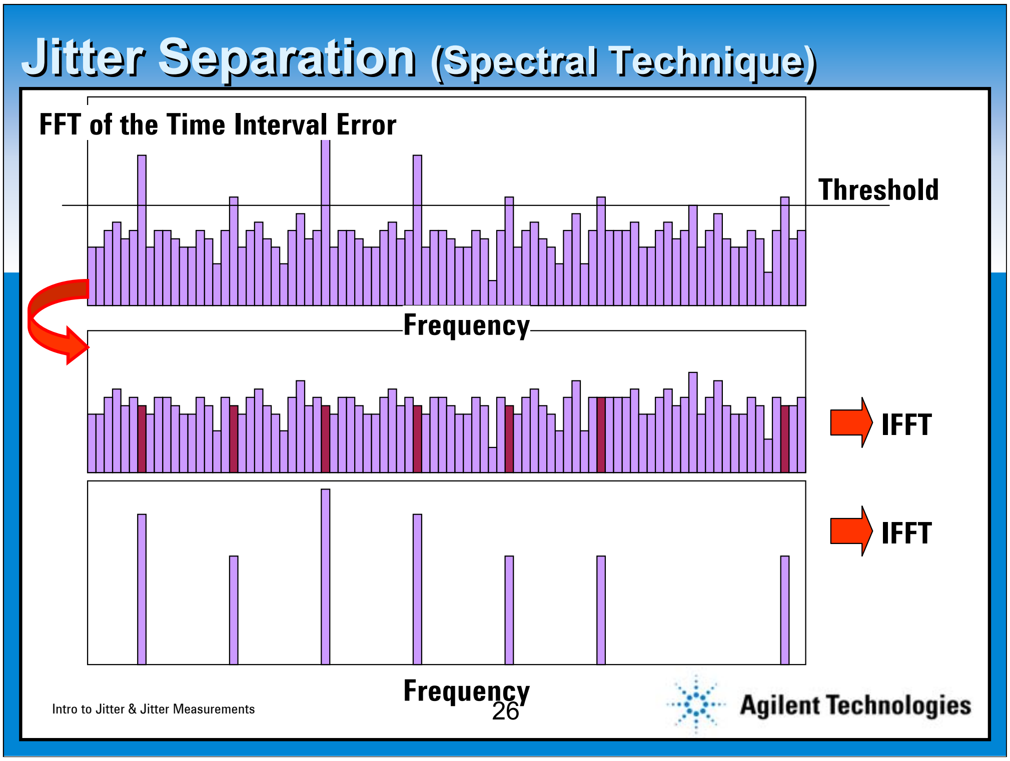
D= DCA-J



The pdf or histogram is used and the tails on the extremes are fit (shown here in red). It is conceptually easy to understand, however, it suffers from typical extrapolation weaknesses. In order to be clear of ANY deterministic jitter (very simply shown as the location of the peaks), you need to have a a sufficient number of hits at least 3 sigma away from the mean (u_R). The population to curve fit then is a VERY small fraction of the total number of hits. In low population areas, anomalies play havoc with mathematics and you have great sensitivity to these and nonrepeatability results.



Another variation on the preceding theme which assumes the dual dirac model is to curve fit the bathtub function in a select range. In the diagram shown, those areas close to either side are considered to be from determinstic sources, so we use a section of the curve which is far enough away from the deterministic region. Using the complementary error function with unknown sigma and mean, a number of points (typically 4 or 5) are used in each side to estimate these parameters. This method allows one to only get the data they need to make the evaluation (by positioning sampling point). However, it suffers in accuracy because of the dual dirac assumption.



The Spectral Technique advanced by Tektronix is much more clever than the preceding jitter separation techniques. The foundational assumption that this is based upon is that all deterministic jitter will be converted to spurs in the frequency domain. When we understand that many non-correlated sources have relatively fixed frequencies and that all the data correlated sources are associated with the 1/(max data rate) by a divide number, we see that this greatly simplifies the task. The other assumption is that the RJ noise is essentially the spectrum noise floor.

So a time record is taken (actually many) and the time interval error measurement is made by software clock recovery techniques. The array of TIE values is FFT'd into the frequency domain, where spurious is revealed and then threshold detected. For those bins with magnitudes above the threshold, these are deterministic sources. Those below are effectively noise and will be part of the RJ calculation. The bins with values above the noise floor are separated out and Inverse FFT'd to yield a time waveform which determine maximum Deterministic jitter. The same process can be done with the noise floor…after removal of the spurious bins, the nearby bins are averaged to estimate the broad band noise that would have been found. The IFFT will yield a random jitter TIE which can be evaluated for sigma easily.

The downfall of this method apparently is to choose the threshold well

Tools to Measure/Analyze Jitter

	Transmitter	Media	Receiver
Bit Error Ratio Tester	x	x	X
Real Time Oscilloscope	X	x	
Equivalent Time Oscilloscope	X	x	
Time Interval Analyzer	X	x	
Vector Network Analyzer		X	
Time Domain Reflectometer		X	
Phase Noise Analyzer	X		
Pattern Generators		x	X

Now its time for folks to pay for the free lunch. We are here to sell products---hopefully products you know you need. The segmentation of jitter concern areas works well for the various product types.

This chart quickly shows appropriate products depending on the jitter task you might have. The most dominant need is clearly in jitter measurement where BERTs, Scopes, DCAs and Time Interval Analyzers are used. Most common are the oscilloscopes. As data rates are pushed, the media plays a huge role in the system jitter budget and VNAs and TDRs are used to evaluate. When it comes to evaluating Receiver circuits, BERTs and Pattern generators are jitterable thus allowing jitter tolerance testing.

Jitter Analysis (BERTs)

Pros

Measures Total Jitter Directly
Can Provide good estimate of total Jitter quickly with BERTScan method
System Tool: Usable for Media analysis, receiver stress analysis

Cons

Expensive
Time of Measurement of Total Jitter is Long
Need an external clock provided

Jitter Analysis (Real Time Oscilloscopes)

Pros

Captures contiguous time record
No external clock required
Software clock recovery methods yield precise clock reconstruction
System Tool: Usable for Debug
Flexibility for many technologies and usually a growth path provided
Many views provided for insight: histograms, eyes, fft, trend, data, etc
Oscilloscope Bandwidths are going higher

Cons

Expensive
Limited to current BW of scope
Estimate of Total Jitter Only
Jitter Measurement packages don't handle ISI very well

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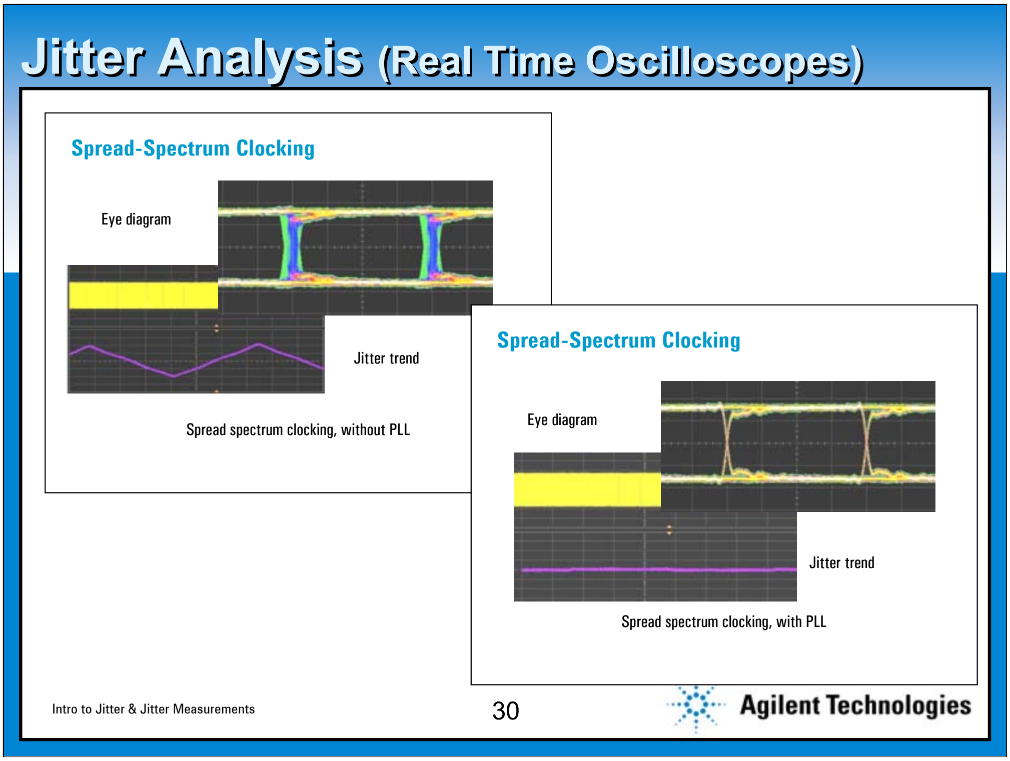
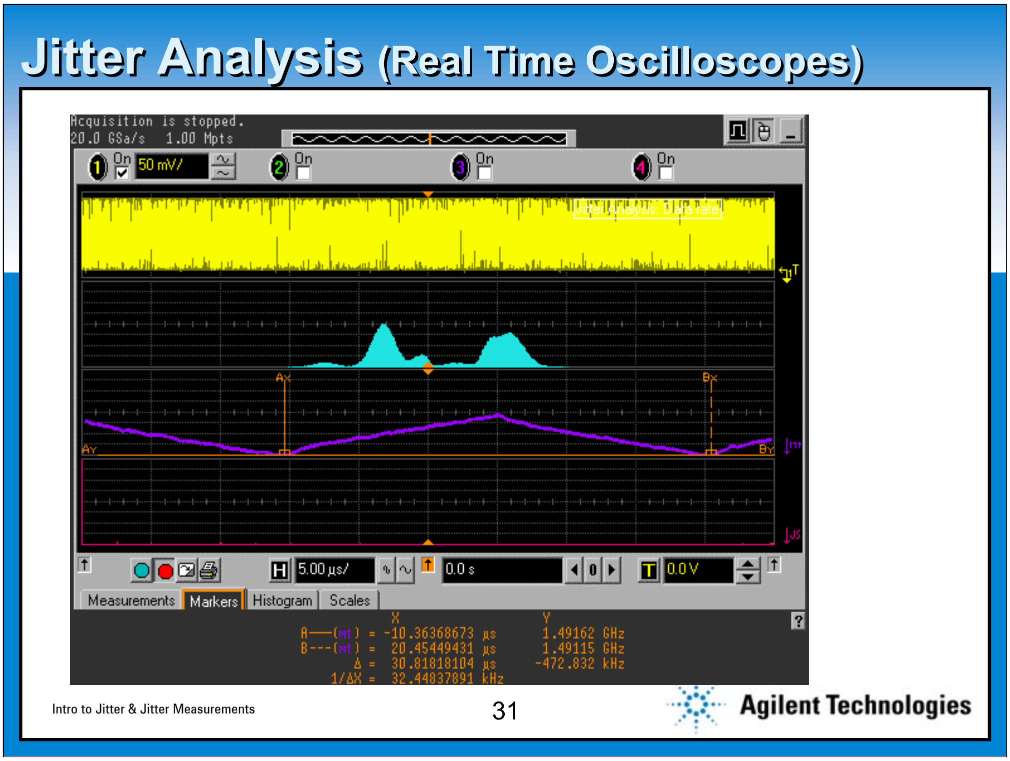
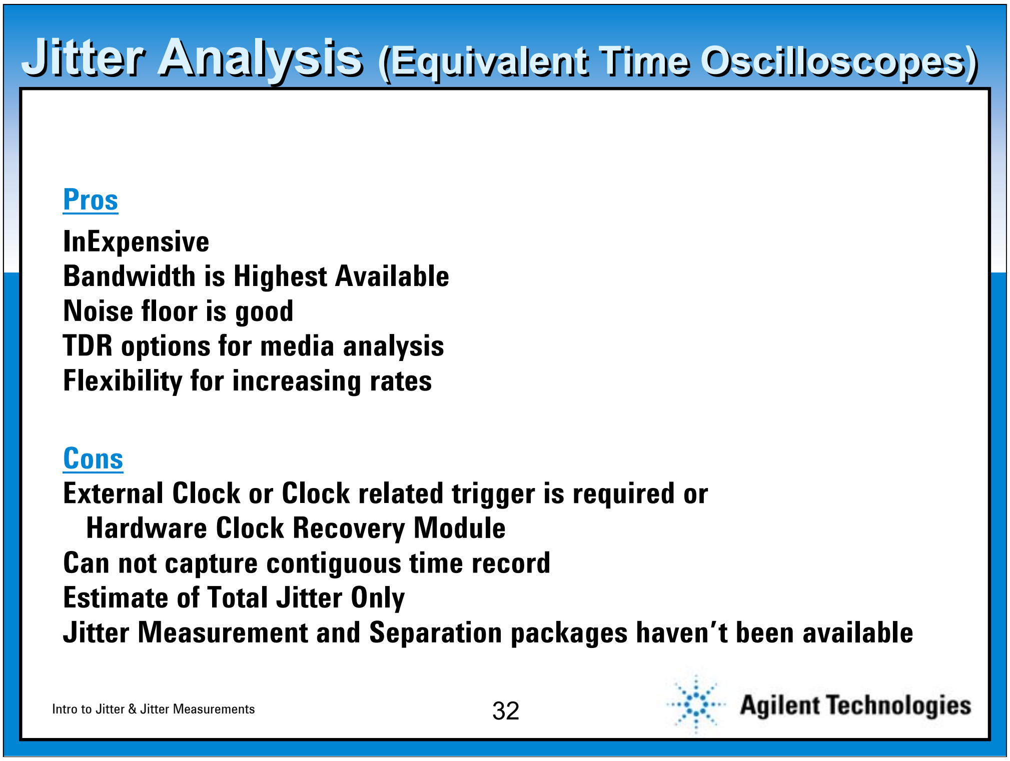


Using a realtime oscilloscope you can capture the whole contiguous record and then recover the clock in software very accurately. This recovered clock can then be used to measure jitter in the data. This graph shows that. In the top graphic we have SATA spread spectrum clock being measured with no clock recovery….I.e. fixed frequency clock. Note the jitter around the crossing points. When we turn on the clock recovery most of this jitter goes away…. Bottom graphic.



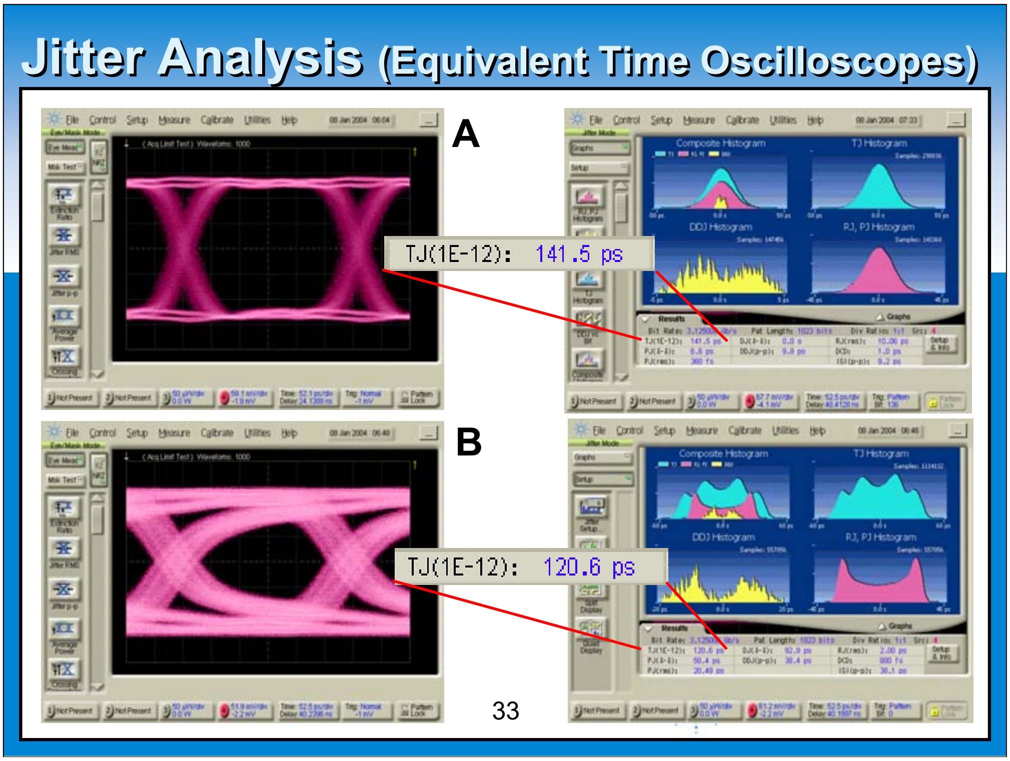
To illustrate why oscilloscopes are the tool of choice, here we see four more views that can help bring insight into your design. The top display is the actual data…which is all grouped together here but could be scaled better for examination. In blue, the second view, we have a histogram which is anything BUT gaussian! The third view in purple shows jitter trend which is time error vs time (you can see why this is a spread spectrum example). Finally, at the bottom in red is the jitter spectrum. It is not particularly well contrasted here.

Downsides of oscilloscopes is that they are rather limited in Bandwidth.



Equivalent time oscilloscopes or DCAs are the next most commonly used jitter tool. These have very high bandwidth (80 GHz) and can have very low jitter noise floors. In addition, they can be a number of tools in one, sporting TDR modules, as well as clock recovery units for common standards. They offer customers the best growth path through the ever faster digital interfaces coming.

For the downsides identified on the slide, it must be remembered that though it only provides an estimate of total jitter---it is the best estimate in the world---in accuracy, repeatability and in speed (DCA-J).



And now the answer the question posed before! Which one has more jitter? Well, these two conditions were measured on the DCA-J whose result displays are shown on the right and are very detailed—too detailed to go into now. However the answer is that Figure A has MORE jitter… because it is random jitter and we just haven't waited long enough to see it fill in the eye.

Jitter Analysis: Vector Network Analyzers (VNAs) vs Time Domain Reflectometers (TDRs)

VNAs

Expensive
50 GHz BW available yields high resolution
Highest Accuracy

Full Differential Analysis analysis to show EMI, mode conversion locations
Software Modeling and Analysis Available
S-Parameters for modeling or to estimate ISI contribution of path

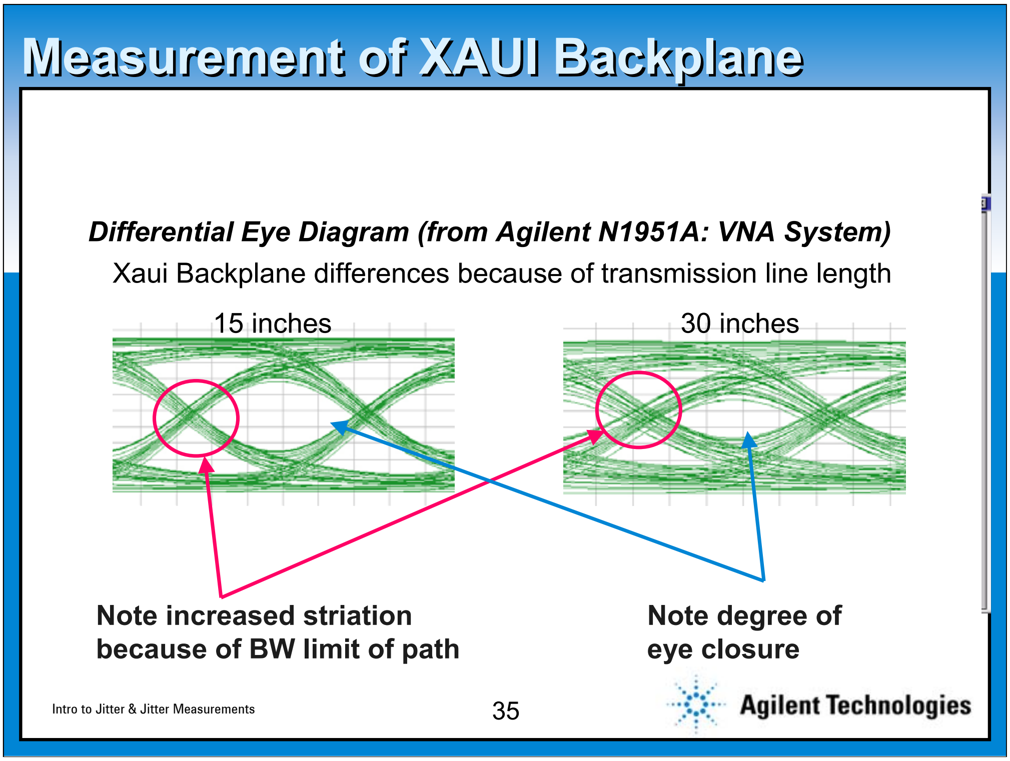
TDRs

InExpensive
Limited by rise time of Pulse source (35ps)
Accuracy may be sufficient in many environments. Using Normalization to increases accuracy
Only magnitude TDT and TDR

Software Modeling and Analysis Available

Describe the VNA and TDR functions.

Point out that a recent web seminar (Sept 1) compared the TDR to the VNA as well as treated the complex topic of receiver equalization for backplane designs



This slide shows simulated eyes of two different lengths of a XAUI backplane as measured by a VNA. Here we have measured the S-Parameters of the transmission, FFT'd to the time domain (impulse response) and then run a digital bit sequence (from a transmitter with its own impulse response) through this 'filter'. You can see two very bad things happening: the eye gets narrow vertically (closing) and the crossing points have more striation. The eye closes vertically because of media loss vs frequency. It also closes horizontally (ISI) because of variation in spread of early and late trajectories.

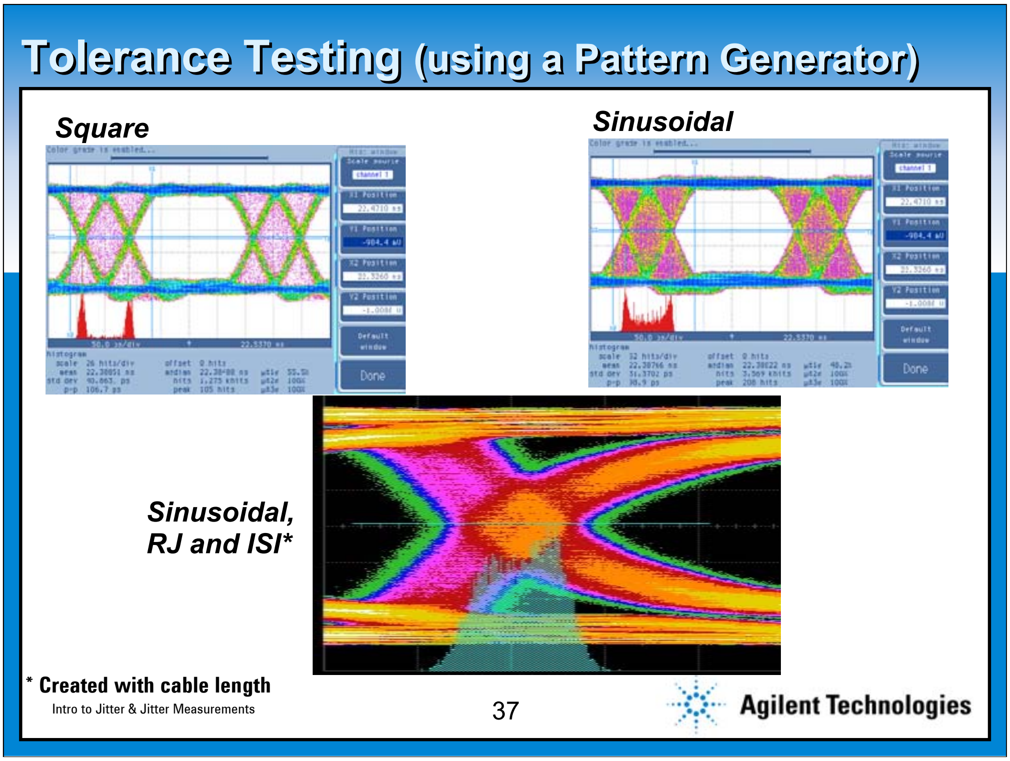
Jitter Tolerance Testing (w/Pattern Generators)

Pros

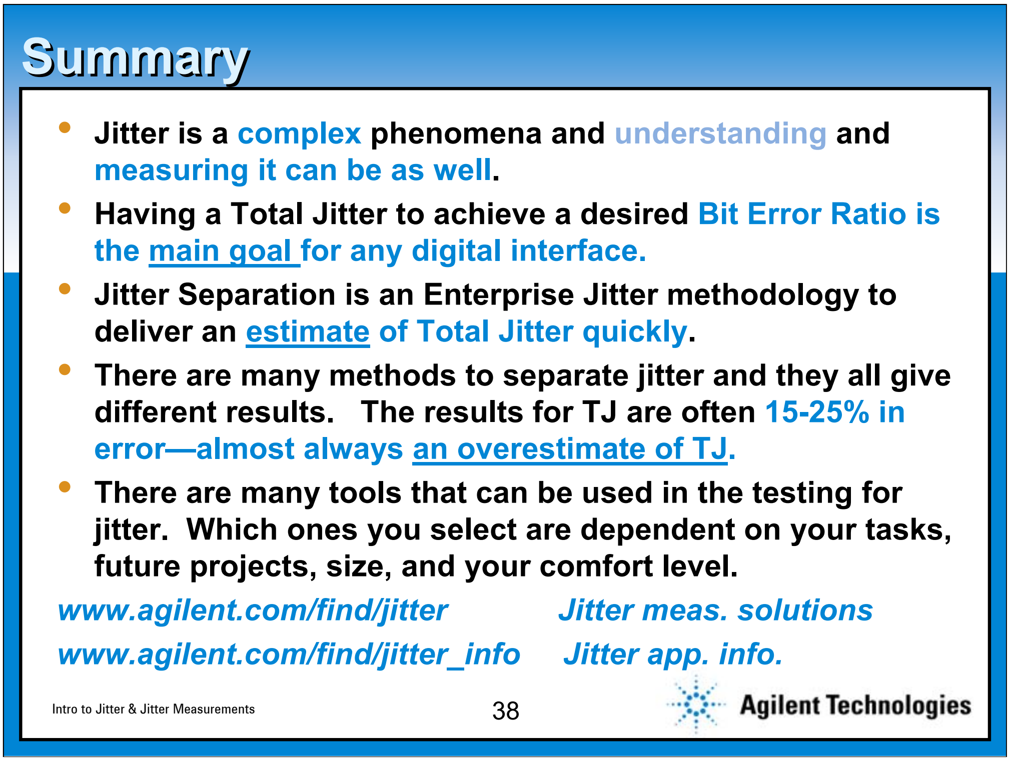
Low Noise (RJ) available
Standard Patterns and User Definable Patterns
Flexible for wide variety of technologies.
RJ, PJ, and DCD can be created.

Cons

Cost Range: Modestly to Highly Expensive
Intersymbol Interference is not available.
Complex sequencing not available.



This shows the creation of jitter using the pattern generator (81134). The top left illustrates a square wave jitter source… (How do you know?) On top right, this is a sinusoidal jitter source. In the middle is a crossing point and associated histogram of composite jittered signal with Random Jitter being added as well as ISI by the inclusion of a cable that was added.



With respect to TJ measurement error—indicate that this is dependent on the type of jitter being measured--- often ISI jitter gets confused with RJ and causes the overestimate because of the x14 factor that is generally applied to RJ.