- Slides 1-5: Industry Buzz
- Slides 6-68: Characterizing Low Jitter eSeminar

Agilent Technologies

THE 40G
INDUSTRY BUZZ

June 4, 2002

presented by:

Larry DesJardin

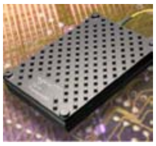
40G: The Short Reach Opportunity

- 40G will cross cost/bit barrier here first
- Best for interconnecting equipment
- Longer Reach follows

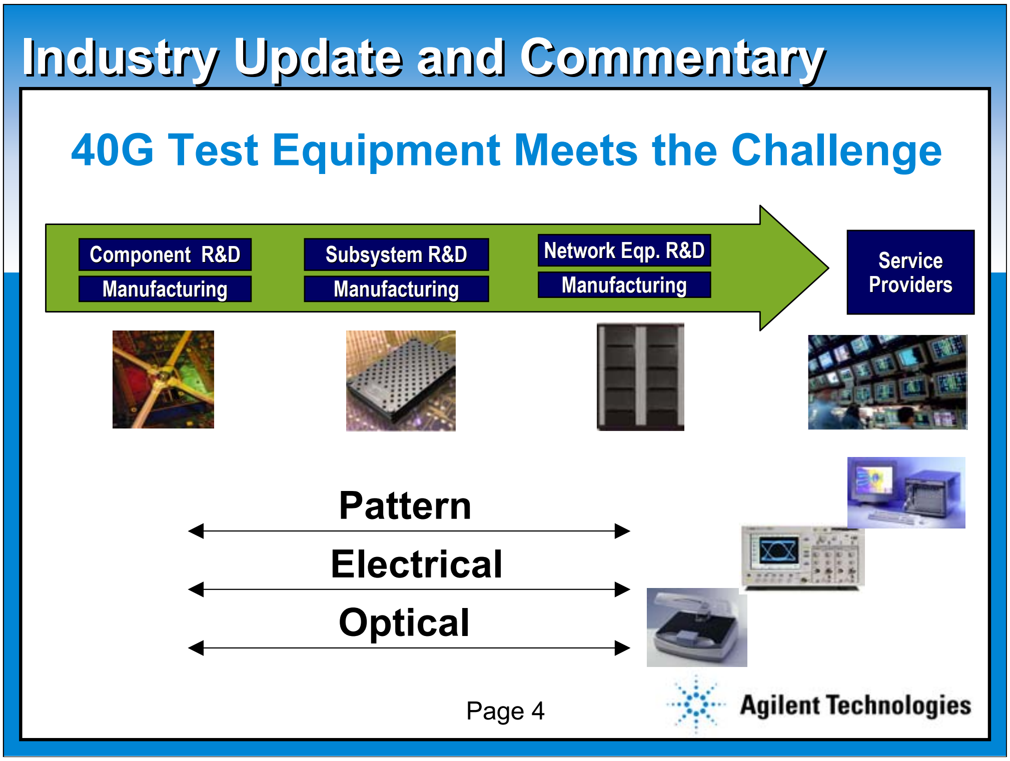
Industry Update and Commentary

40G + Short Reach …..why?

- SFI-5 Standards based transponders
- Semiconductor advances
- EA Modulators
- Packaging Technology
- Test Equipment



Agilent Technologies



Industry Update and Commentary

40G Test Equipment Meets the Challenge

Component R&D
Manufacturing

Subsystem R&D
Manufacturing

Network Eqp. R&D
Manufacturing

Service Providers

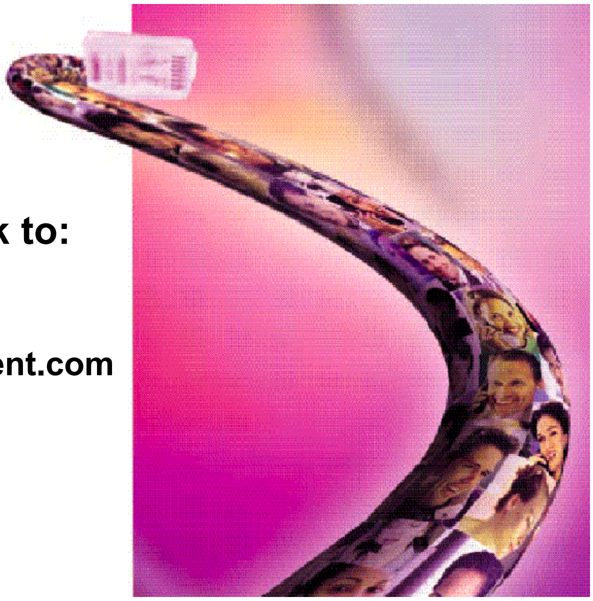
Pattern

Electrical

Optical

Agilent Technologies

THE 40G
INDUSTRY BUZZ



Send any feedback to:

larry_desjardin@agilent.com

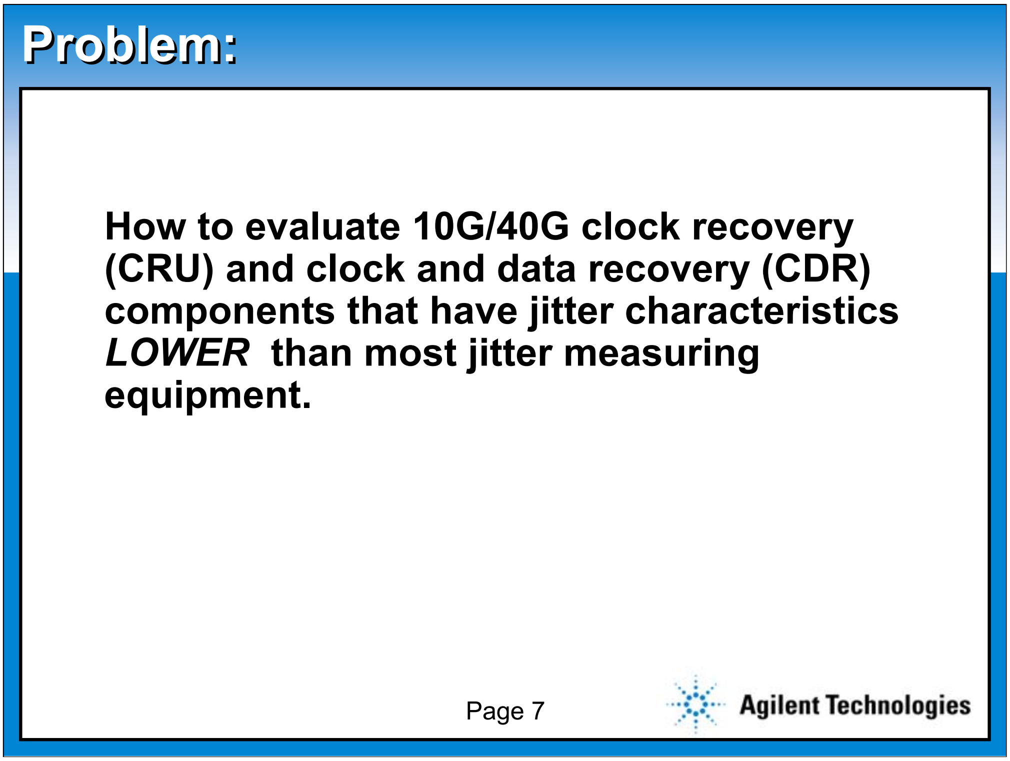
Agilent Technologies

Characterizing Low Jitter 10G and 40G Electrical Components for SONET/SDH Applications

June 4, 2002

presented by:

Paul Schmitz

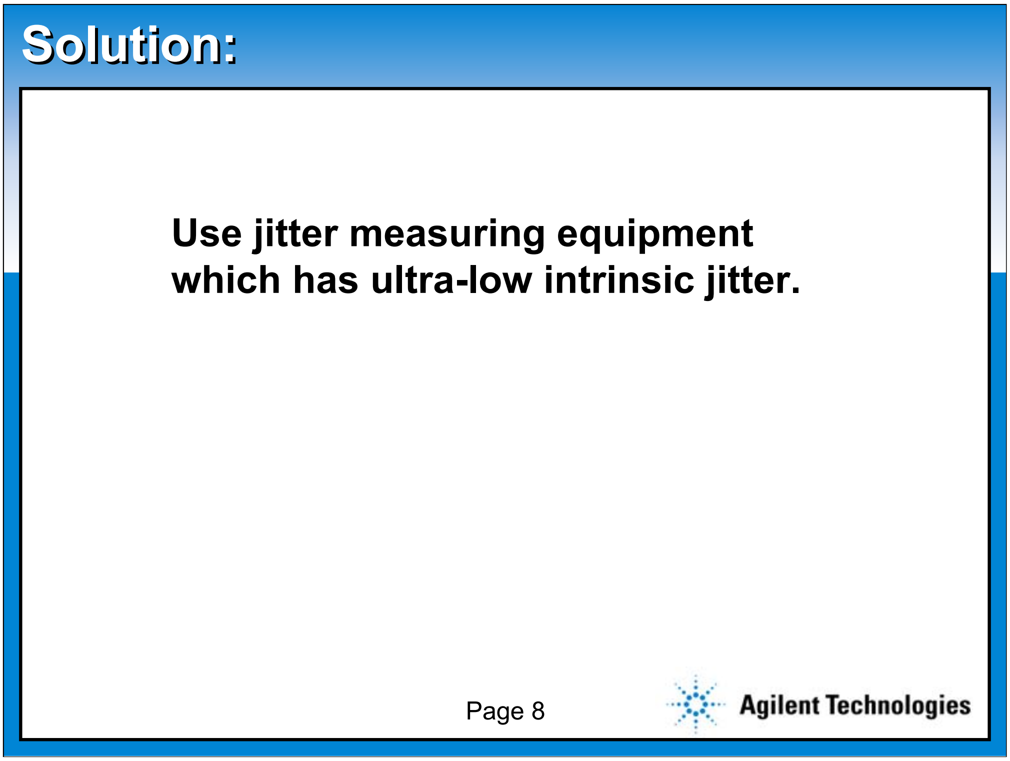


Problem:

How to evaluate 10G/40G clock recovery (CRU) and clock and data recovery (CDR) components that have jitter characteristics *LOWER* than most jitter measuring equipment.

Agilent Technologies

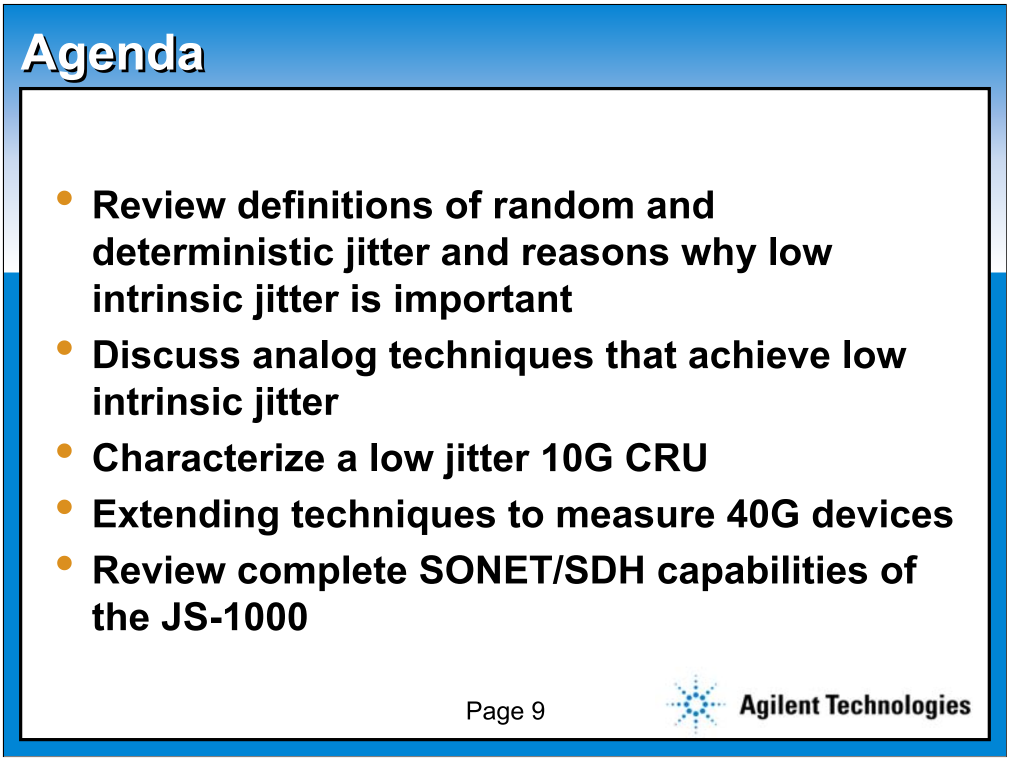
A real problem for many development engineers is how to characterize low jitter electrical devices such as clock recovery or clock and data recovery units when the measuring equipment available has intrinsic jitter levels higher than the device-under-test



Solution:

Use jitter measuring equipment which has ultra-low intrinsic jitter.

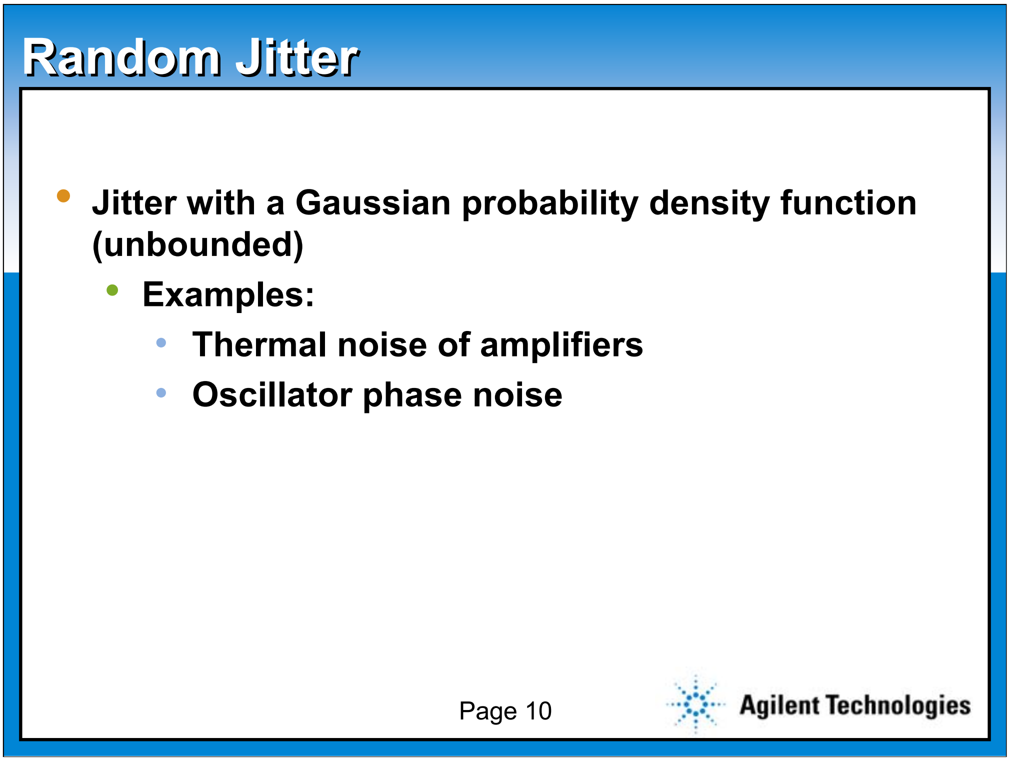
The best answer is to use measurement solutions that have ultra-low intrinsic jitter.



Agenda

- Review definitions of random and deterministic jitter and reasons why low intrinsic jitter is important
- Discuss analog techniques that achieve low intrinsic jitter
- Characterize a low jitter 10G CRU
- Extending techniques to measure 40G devices
- Review complete SONET/SDH capabilities of the JS-1000

Today’s discussion will start with reviewing the classical definitions of jitter and the reasons why low instrinsic jitter is important. Then we will look at high performance analog measurement techniques that achieve ultra-low jitter. Using these techniques, I will show SONET/SDH measurement results of a low jitter 10G clock recovery unit. Finally we will look at how we plan to extend these techniques to 40G components and what solution is available today which provides this capability.

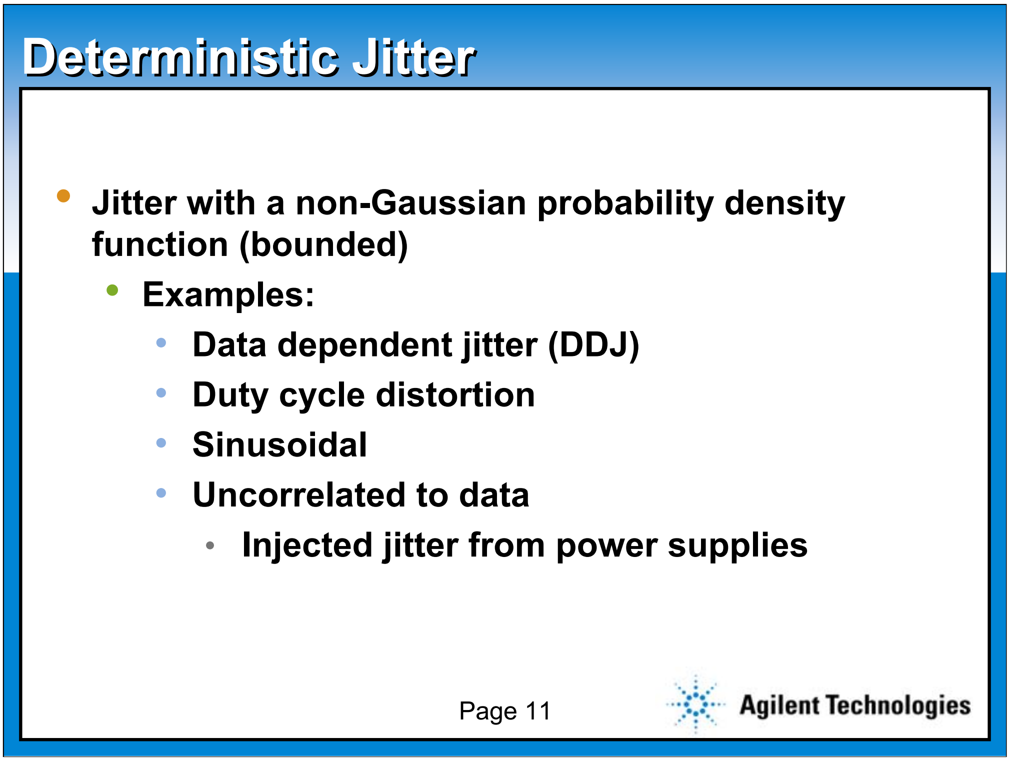


Random Jitter

- Jitter with a Gaussian probability density function (unbounded)
  - Examples:
    - Thermal noise of amplifiers
    - Oscillator phase noise

Agilent Technologies

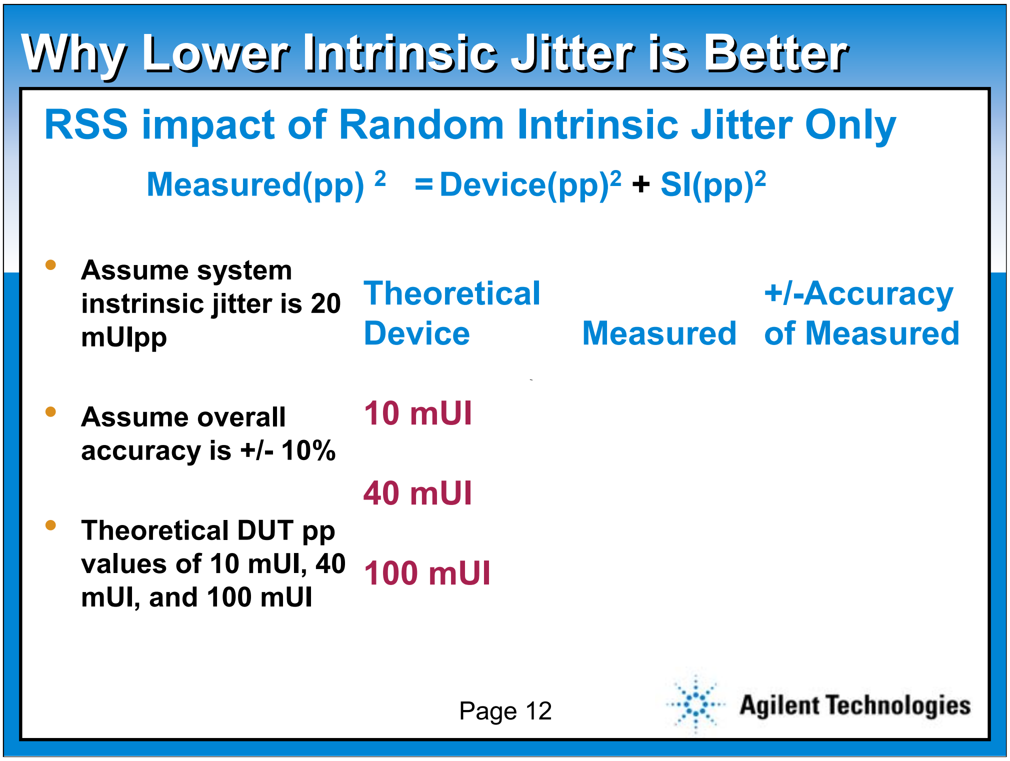
Random Jitter is defined as that jitter which has a Gaussian probability density function. Some examples of Gaussian noise include broadband KTB noise, thermal noise of amplifiers as well as phase noise of oscillators.



Deterministic Jitter

- Jitter with a non-Gaussian probability density function (bounded)
  - Examples:
    - Data dependent jitter (DDJ)
    - Duty cycle distortion
    - Sinusoidal
    - Uncorrelated to data
      - Injected jitter from power supplies

Jitter that is bounded and thus has a non-gaussian probability density function is defined as deterministic jitter. Examples included data dependent jitter, duty cycle distortion, sinusodial and other jitter that is uncorrelated to the data.



Why Lower Intrinsic Jitter is Better

RSS impact of Random Intrinsic Jitter Only

$$\text{Measured(pp)}^2 = \text{Device(pp)}^2 + \text{SI(pp)}^2$$

- Assume system instrinsic jitter is 20 mUIpp
- Assume overall accuracy is +/- 10%
- Theoretical DUT pp values of 10 mUI, 40 mUI, and 100 mUI

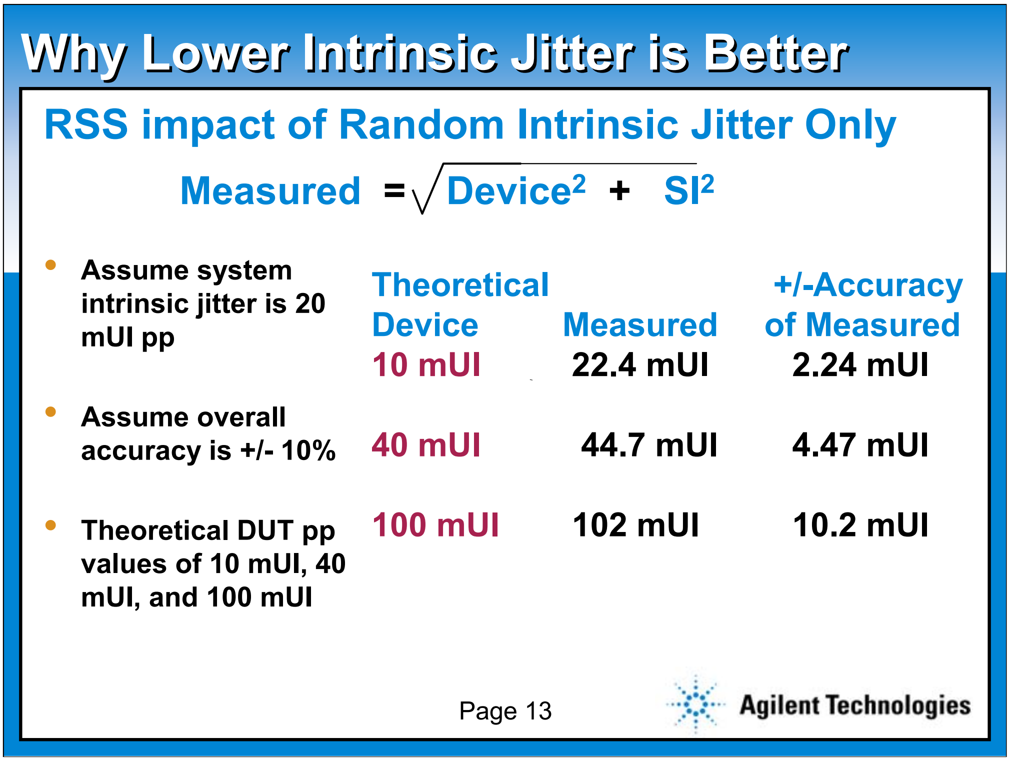
Theoretical Device	Measured	+/-Accuracy of Measured
10 mUI		
40 mUI		
100 mUI		

If we assume that random intrinsic jitter will add to a DUT response in an RSS (root sum square) fashion, we can see why lower system intrinsic jitter is better, especially when characterizing device designs.

Combining the pp jitter of a device with the measurement system intrinsic jitter through RSS means that they add as a sum of power, shown here by summing the squared values of each characteristic. The resulting squared value (measured) is what we would expect to receive from the measurement system.

To demonstrate this, we will make a number of assumptions:

1) The pp system intrinsic jitter is 20 mUI;
2) The overall measurement accuracy of the system is +/- 10%;
3) The theoretical device pp values that we will use are 10 mUI, 40 mUI, and 100 mUI;



Why Lower Intrinsic Jitter is Better

RSS impact of Random Intrinsic Jitter Only

$$\text{Measured} = \sqrt{\text{Device}^2 + \text{SI}^2}$$

- Assume system intrinsic jitter is 20 mUI pp
- Assume overall accuracy is +/- 10%
- Theoretical DUT pp values of 10 mUI, 40 mUI, and 100 mUI

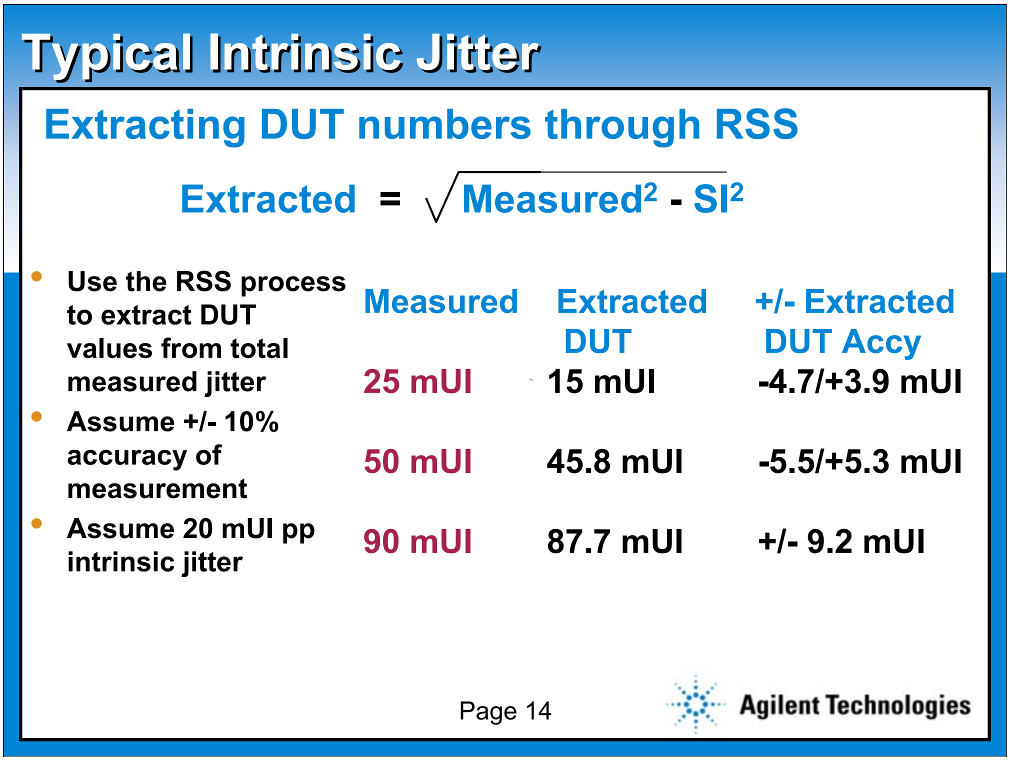
Theoretical Device	Measured	+/-Accuracy of Measured
10 mUI	22.4 mUI	2.24 mUI
40 mUI	44.7 mUI	4.47 mUI
100 mUI	102 mUI	10.2 mUI

Agilent Technologies

To determined the expected measured values, we will take the square root of the sum of the two squares.

Notice that the overall measurement accuracy is based on the total signal that is measured.

Also notice, that a 10 mUI jitter is inaccurately measured, while the higher levels of jitter are reasonably accurate.



Typical Intrinsic Jitter

Extracting DUT numbers through RSS

$$\text{Extracted} = \sqrt{\text{Measured}^2 - \text{SI}^2}$$

- Use the RSS process to extract DUT values from total measured jitter
- Assume +/- 10% accuracy of measurement
- Assume 20 mUI pp intrinsic jitter

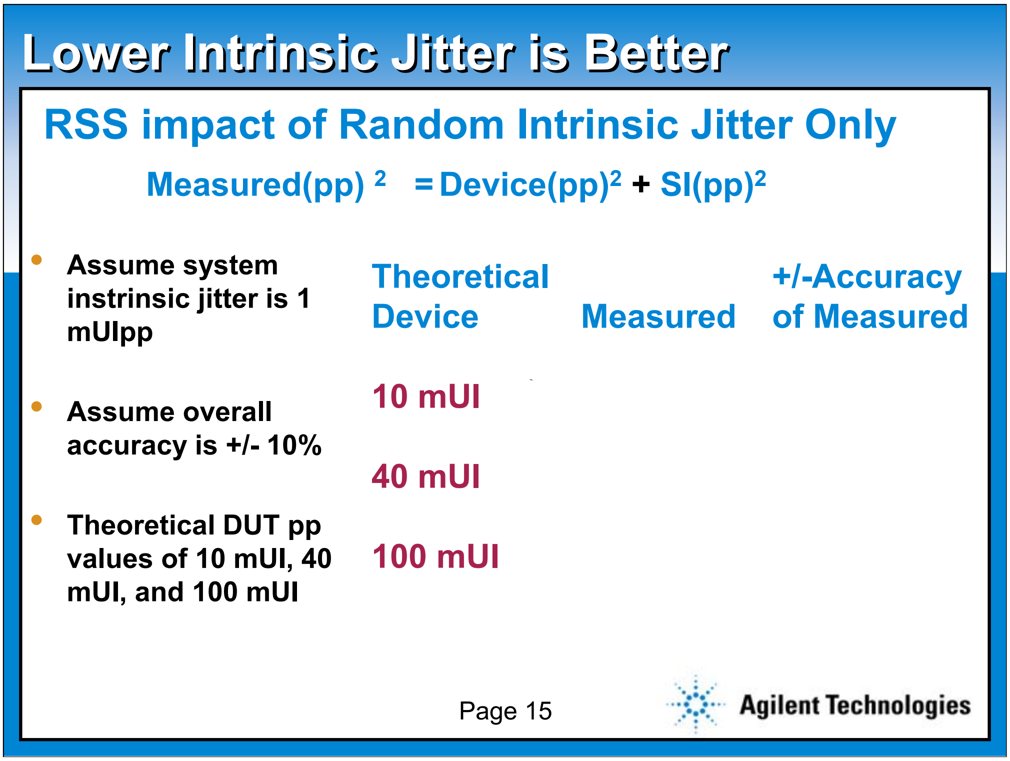
Measured	Extracted DUT	+/- Extracted DUT Accy
25 mUI	15 mUI	-4.7/+3.9 mUI
50 mUI	45.8 mUI	-5.5/+5.3 mUI
90 mUI	87.7 mUI	+/- 9.2 mUI

Agilent Technologies

Real world conditions always has the DUT characteristics as the unknown.

If we use the RSS process to extract a DUT value from total measured jitter, using the same assumptions as before, we notice something very interesting:

1) Measurement accuracy for the DUT extraction must also be determined using the same process – and the accuracy values of the DUT characteristic is NOT 10% of the DUT value for small values of DUT jitter (close to the intrinsic jitter);
2) The smaller the DUT value, the larger the DUT uncertainty will become;
3) The large the DUT value, the DUT uncertainty will converge to the total measured uncertainty.



Lower Intrinsic Jitter is Better

RSS impact of Random Intrinsic Jitter Only

$$\text{Measured(pp)}^2 = \text{Device(pp)}^2 + \text{SI(pp)}^2$$

- Assume system instrinsic jitter is 1 mUIpp
- Assume overall accuracy is +/- 10%
- Theoretical DUT pp values of 10 mUI, 40 mUI, and 100 mUI

Theoretical Device	Measured	+/-Accuracy of Measured
10 mUI		
40 mUI		
100 mUI		

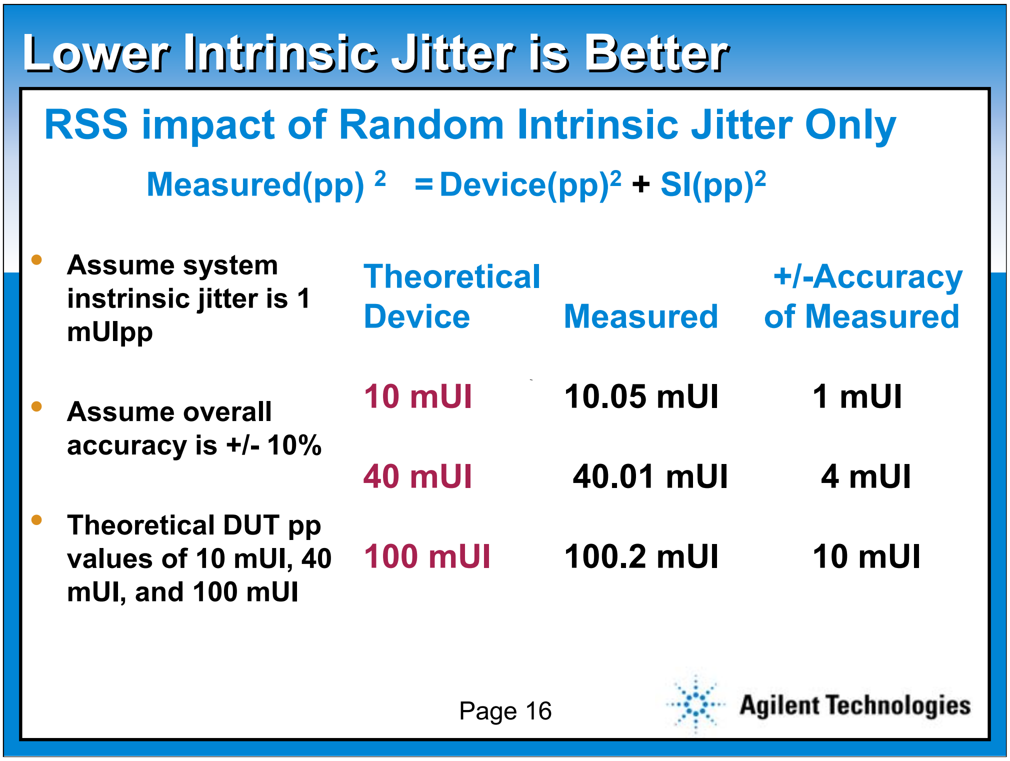
Agilent Technologies

Let’s see what happens if the measurement system that has ultra low intrinsic jitter of 1 mUIpp and we apply the same principals as before.

Combining the pp jitter of a device with the measurement system intrinsic jitter through RSS means that they add as a sum of power, shown here by summing the squared values of each characteristic. The resulting squared value (measured) is what we would expect to receive from the measurement system.

To demonstrate this, we will make a number of assumptions:

1) The pp system intrinsic jitter is 1 mUI;
2) The overall measurement accuracy of the system is +/- 10%;
3) The theoretical device pp values that we will use are 10 mUI, 40 mUI, and 100 mUI;



Lower Intrinsic Jitter is Better

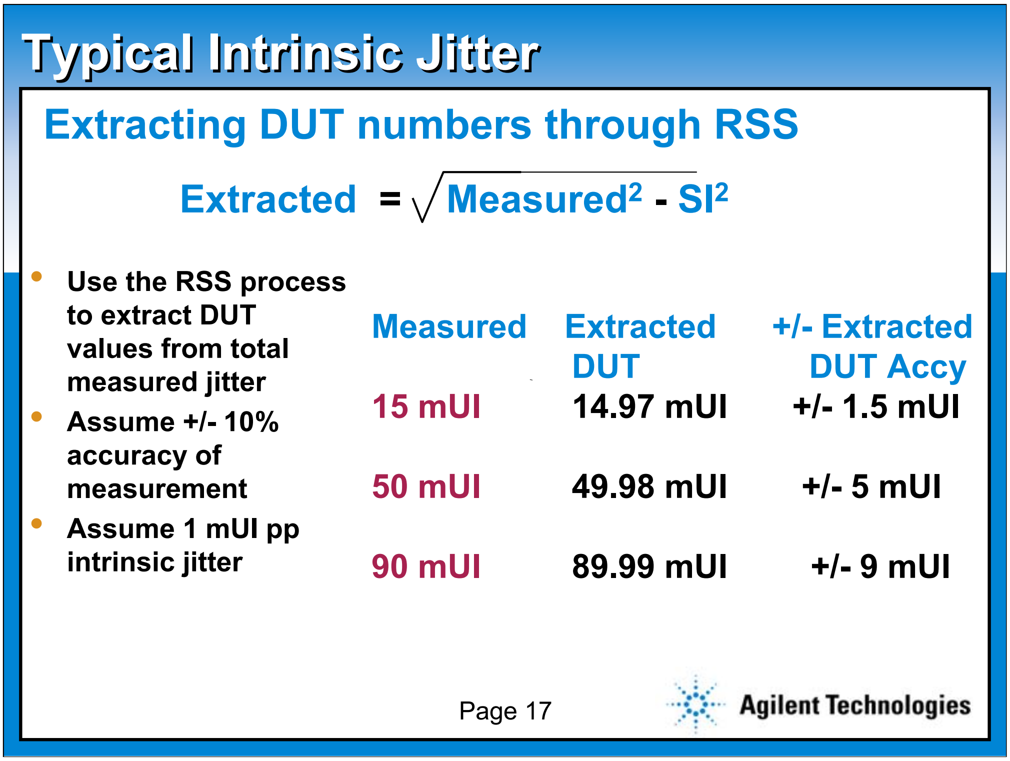
RSS impact of Random Intrinsic Jitter Only

$$\text{Measured(pp)}^2 = \text{Device(pp)}^2 + \text{SI(pp)}^2$$

- Assume system instrinsic jitter is 1 mUIpp
- Assume overall accuracy is +/- 10%
- Theoretical DUT pp values of 10 mUI, 40 mUI, and 100 mUI

Theoretical Device	Measured	+/-Accuracy of Measured
10 mUI	10.05 mUI	1 mUI
40 mUI	40.01 mUI	4 mUI
100 mUI	100.2 mUI	10 mUI

Even though the measurement system has the same measurement accuracy as before, the expected results will have better overall accuracy.



Typical Intrinsic Jitter

Extracting DUT numbers through RSS

$$\text{Extracted} = \sqrt{\text{Measured}^2 - \text{SI}^2}$$

- Use the RSS process to extract DUT values from total measured jitter
- Assume +/- 10% accuracy of measurement
- Assume 1 mUI pp intrinsic jitter

Measured	Extracted DUT	+/- Extracted DUT Accy
15 mUI	14.97 mUI	+/- 1.5 mUI
50 mUI	49.98 mUI	+/- 5 mUI
90 mUI	89.99 mUI	+/- 9 mUI

When the measurement system has lower intrinsic jitter, the accuracy of the extracted DUT value is essentially the same as the accuracy of the measurement.

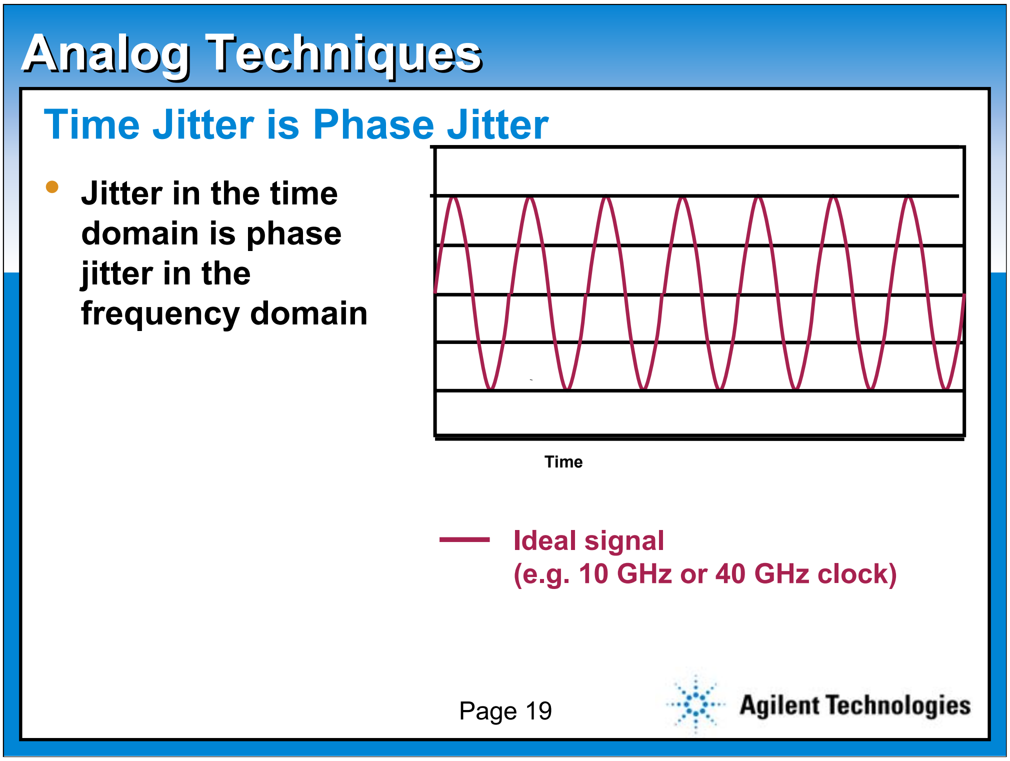
Analog Techniques

Time Jitter is Phase Jitter

Agilent Technologies

If we are going to have a system with low intrinsic jitter, we need to make jitter measurements using different techniques than the traditional time domain techniques that are currently being used.

First we will demonstrate that time jitter (in the time domain), is equivalent to phase jitter in the frequency domain.



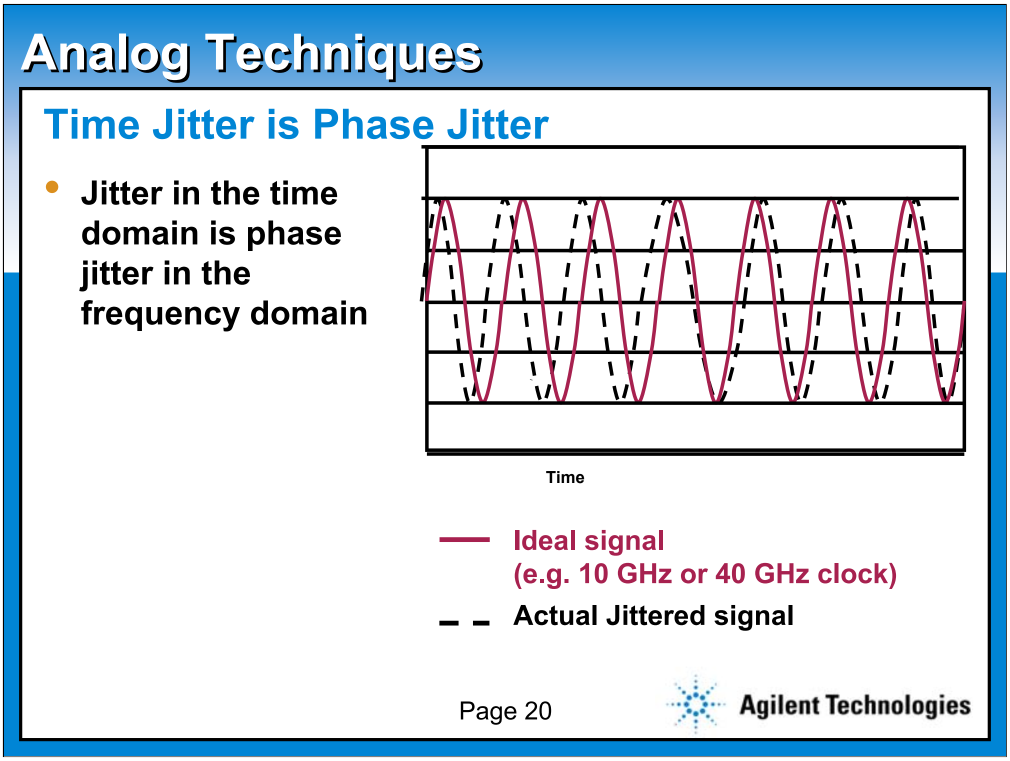
Analog Techniques

Time Jitter is Phase Jitter

- Jitter in the time domain is phase jitter in the frequency domain

Ideal signal
(e.g. 10 GHz or 40 GHz clock)

We will start with an ideal signal – like a clock signal – that has no jitter.



Analog Techniques

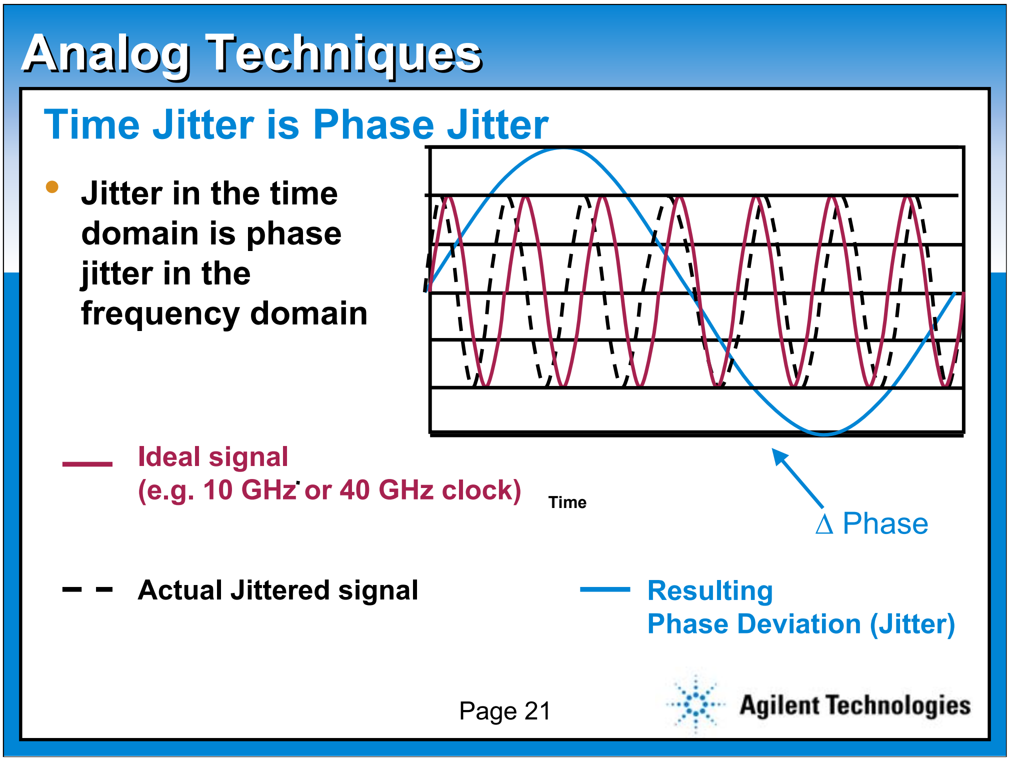
Time Jitter is Phase Jitter

- Jitter in the time domain is phase jitter in the frequency domain

— Ideal signal (e.g. 10 GHz or 40 GHz clock)

– – Actual Jittered signal

As shown here, we have applied jitter to vary the zero crossings of the ideal signal. In the left half of the example, the jittered signal zero crossings lead the ideal and in the right half, the jittered zero crossings lag the ideal.



Analog Techniques

Time Jitter is Phase Jitter

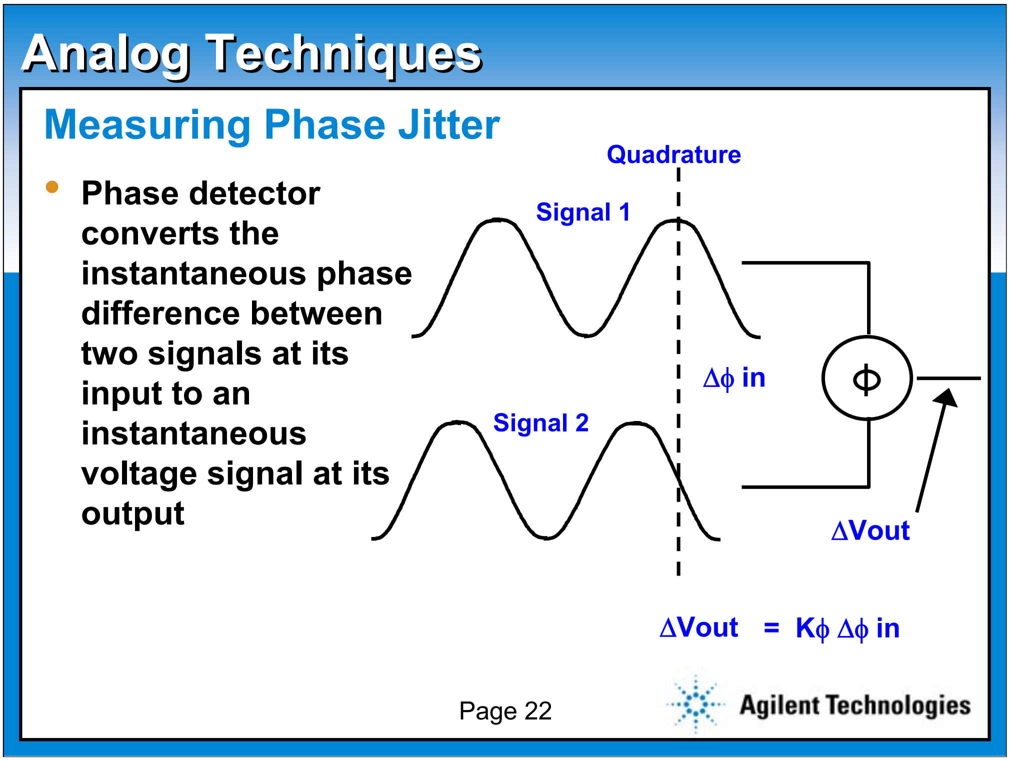
- **Jitter in the time domain is phase jitter in the frequency domain**

Ideal signal (e.g. 10 GHz or 40 GHz clock)

Actual Jittered signal

Resulting Phase Deviation (Jitter)

The overall result in the frequency domain is a phase deviation that is positive in the left half and negative in the right half. Phase deviations, using analog techniques within frequency domain approaches can be measured to very low levels.



Analog Techniques

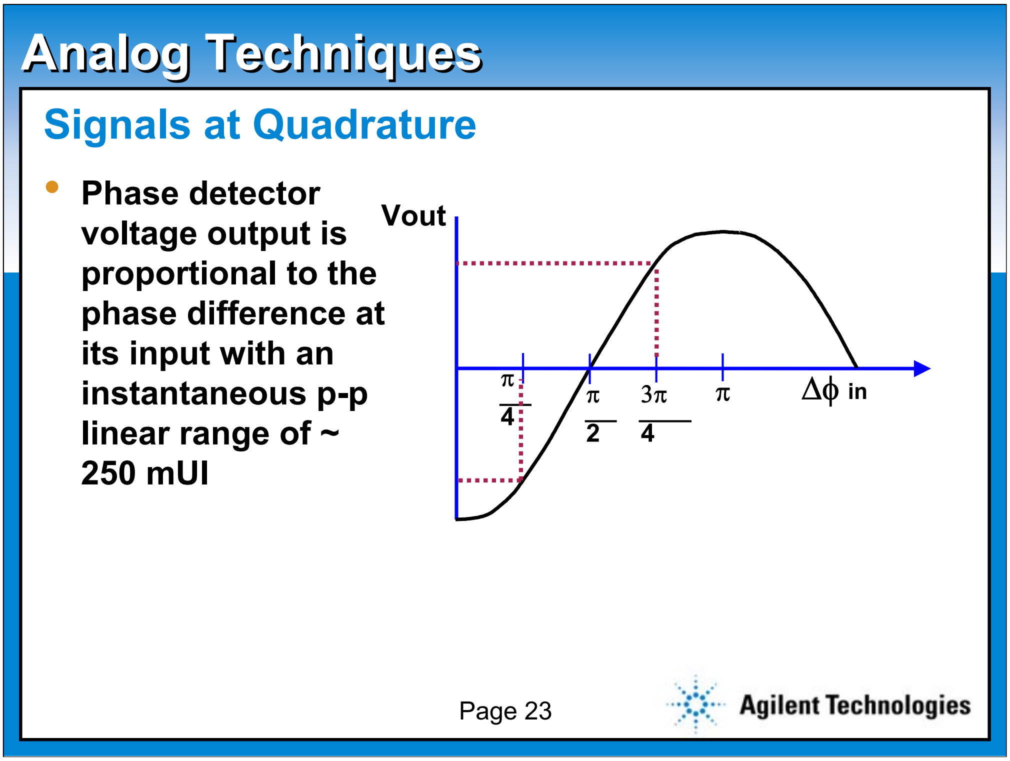
Measuring Phase Jitter

- Phase detector converts the instantaneous phase difference between two signals at its input to an instantaneous voltage signal at its output

$\Delta\text{Vout} = K\phi\ \Delta\phi\ \text{in}$

The basic phase measurement device within the frequency domain is the analog phase detector. It requires two input signals of the same frequency to detect a phase difference (a reference signal and a test signal).

If the two signals are in quadrature (90 degree difference), the output of the phase detector becomes 0 Volts. Thus any instantaneous phase difference between the two signals appears as an instantaneous voltage difference at the output. The phase detector constant in volts/rad relates the output voltage to the input phase difference.

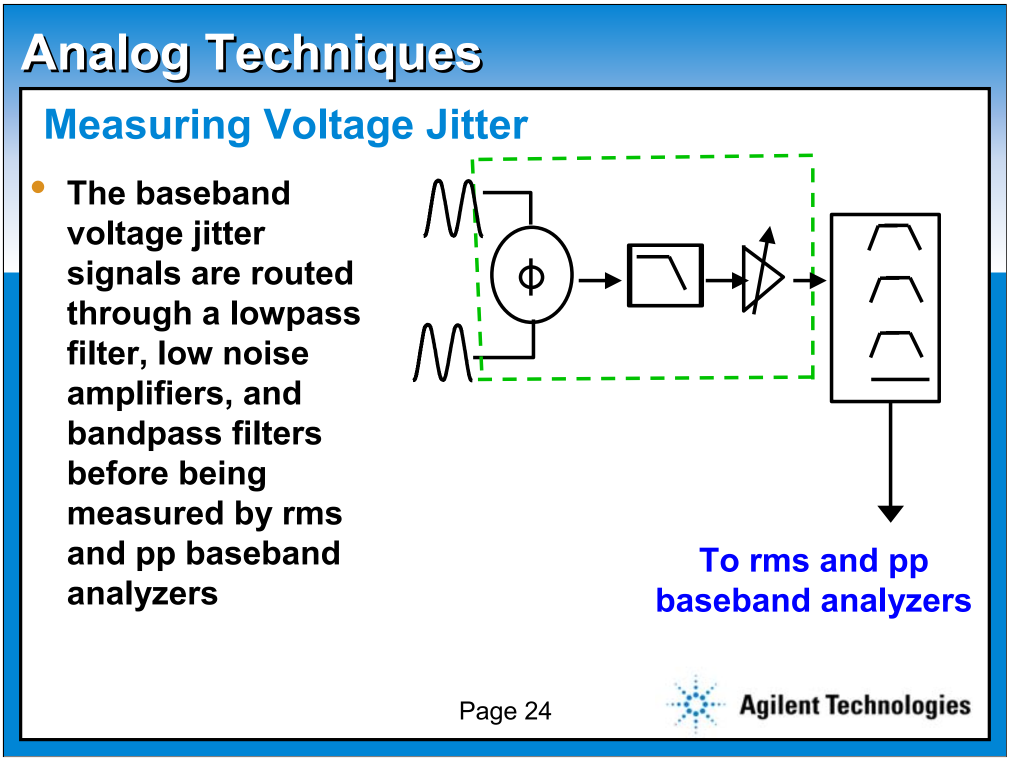


Analog Techniques

Signals at Quadrature

- Phase detector voltage output is proportional to the phase difference at its input with an instantaneous p-p linear range of ~ 250 mUI

With the phase difference at the input of the phase detector fixed at 90 degrees, the range of linear instantaneous phase changes detectable is approximately +/- 1/8 of a Unit Interval (UI) or a p-p range of 1/4 UI (250 mUI).



Analog Techniques

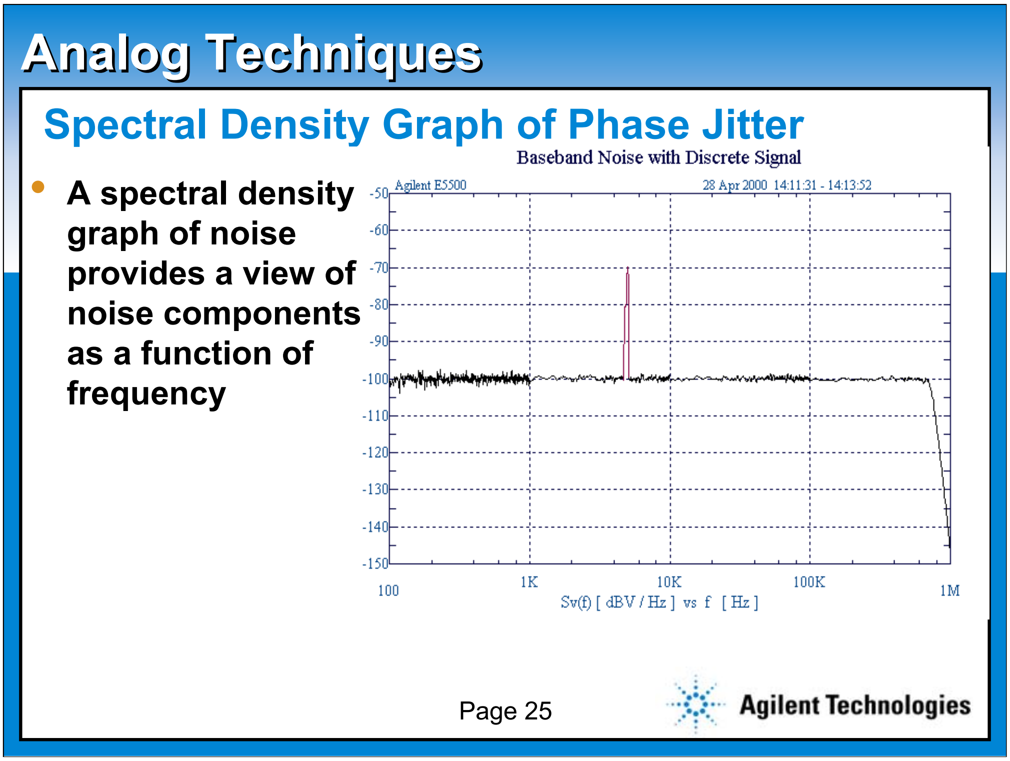
Measuring Voltage Jitter

- The baseband voltage jitter signals are routed through a lowpass filter, low noise amplifiers, and bandpass filters before being measured by rms and pp baseband analyzers

To rms and pp baseband analyzers

The instantaneous voltage signals produced are then processed through a low pass filter and low noise amplifiers. The LPF is used to protect the LNAs, and the LNAs are used to amplify the voltage signal to a level that allow relatively inexpensive rms and p-p baseband analyzers to measure them accurately. Required SONET filtering for p-p measurements is implemented at baseband frequencies.

This general measurement technique has been employed by Agilent within accurate phase noise measurement solutions for > 20 years.

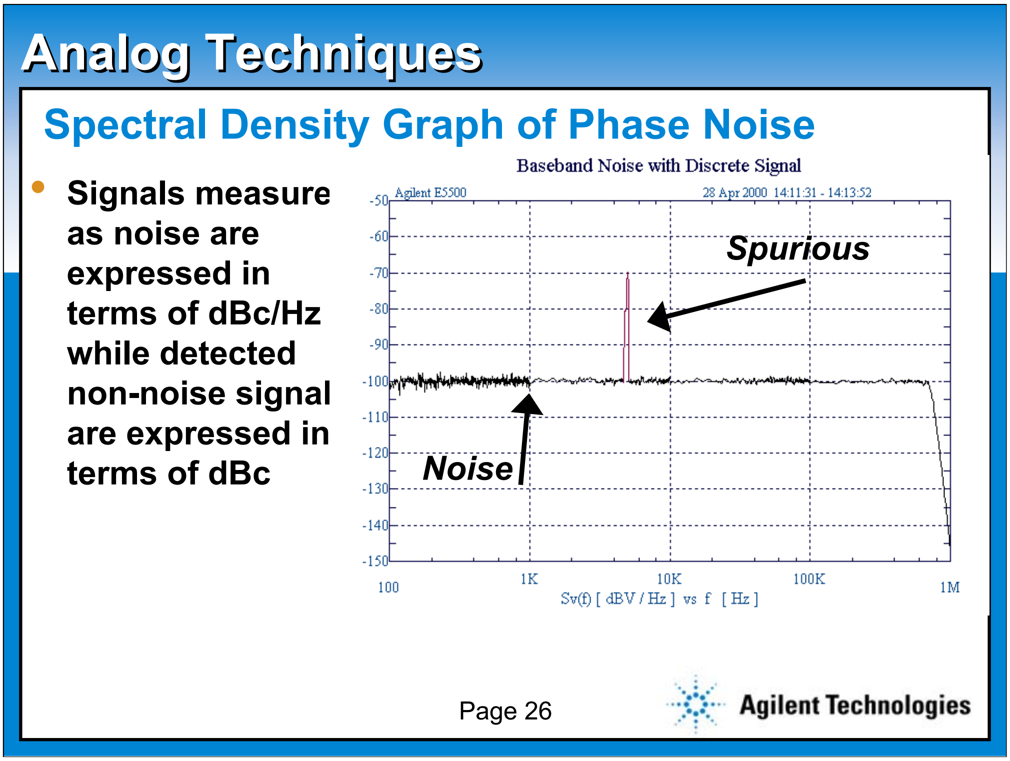


Analog Techniques

Spectral Density Graph of Phase Jitter

- A spectral density graph of noise provides a view of noise components as a function of frequency

An example of frequency domain information provided is shown here. Noise (random) signals and non-noise signals are displayed. This particular example is broadband noise that has a discrete (non-random) signal within it.

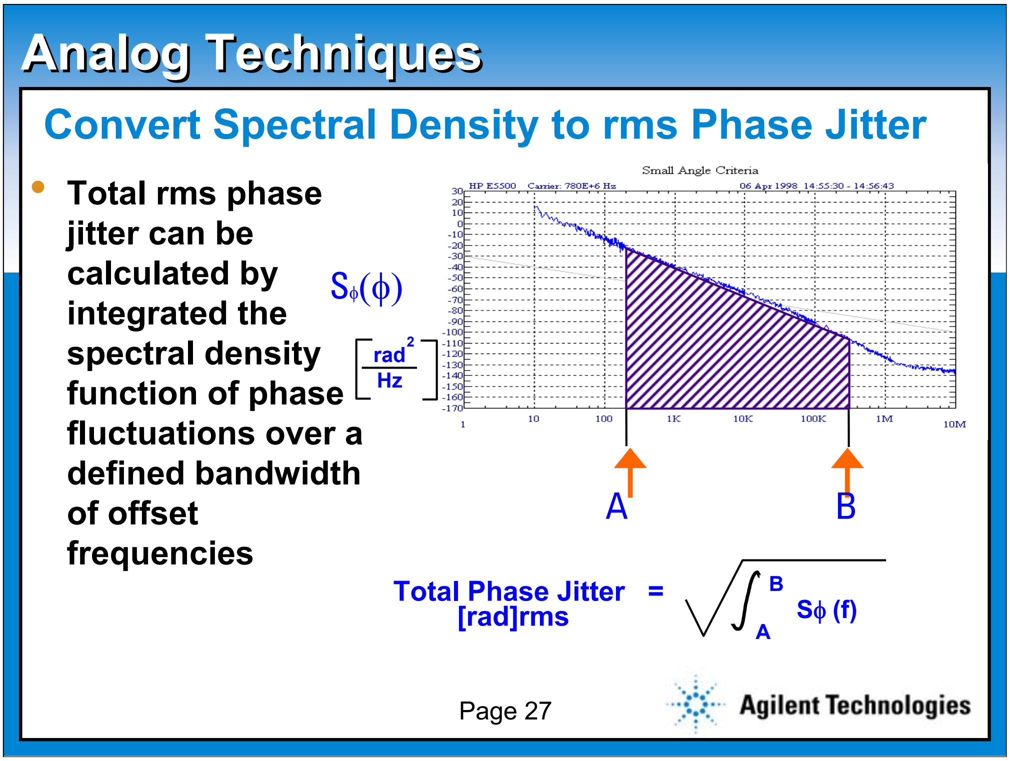


Analog Techniques

Spectral Density Graph of Phase Noise

- **Signals measure as noise are expressed in terms of dBc/Hz while detected non-noise signal are expressed in terms of dBc**

Noise terms (vertical axis) are plotted in a 1 Hz bandwidth and expressed in terms of dBc/Hz (dB below the carrier in a 1 Hz bandwidth) as a function of offset frequency from the carrier signal (horizontal axis). Detected non-random signals are expressed in their normal dBc value (they are not normalized to a 1 Hz bandwidth value).



Analog Techniques

Convert Spectral Density to rms Phase Jitter

- Total rms phase jitter can be calculated by integrated the spectral density function of phase fluctuations over a defined bandwidth of offset frequencies

$S_\phi(\phi)$ $\left[\frac{rad^2}{Hz}\right]$

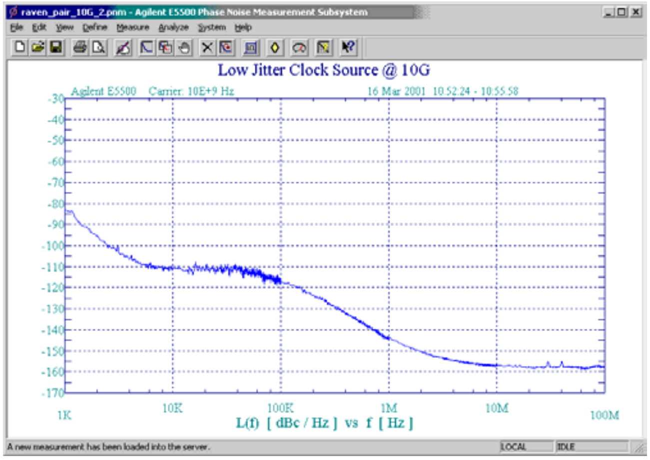
Total Phase Jitter [rad]rms $= \sqrt{\int_A^B S\phi\,(f)}$

If we display the spectral density of phase fluctuations (Sphi(f)) which has the units of radians^2/Hz, we can obtain total rms phase jitter by integrating the Sphi(f) results over an offset frequency range (bandwidth) of interest.

Analog Techniques

Low Jitter of a 10G Clock

- Here is an example measurement of a low jitter 10G clock


raven_pair_10G_2.pnm - Agilent E5500 Phase Noise Measurement Subsystem

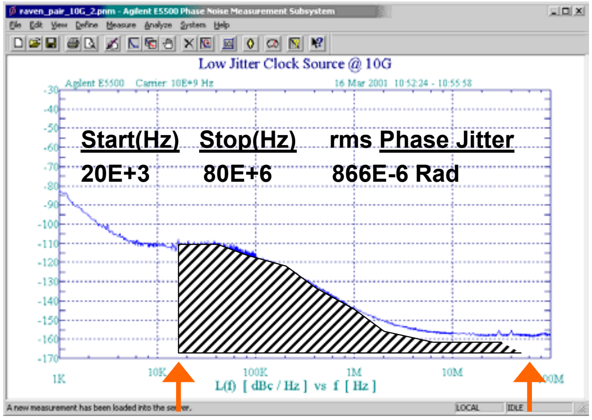
A new measurement has been loaded into the server.

To illustrate this process, we will determine the rms phase jitter of a low noise 10G clock signal. As you can see here, the noise of this signal approaches –160 dBc/Hz phase noise for offsets far from carrier (> 10 MHz).

Analog Techniques

Low Jitter of a 10G Clock

- Total rms phase jitter is obtained by integrating the spectral density function over a 20kHz to 80 MHz bandwidth
- rms UI jitter can be determined by dividing the rms phase jitter by 2π

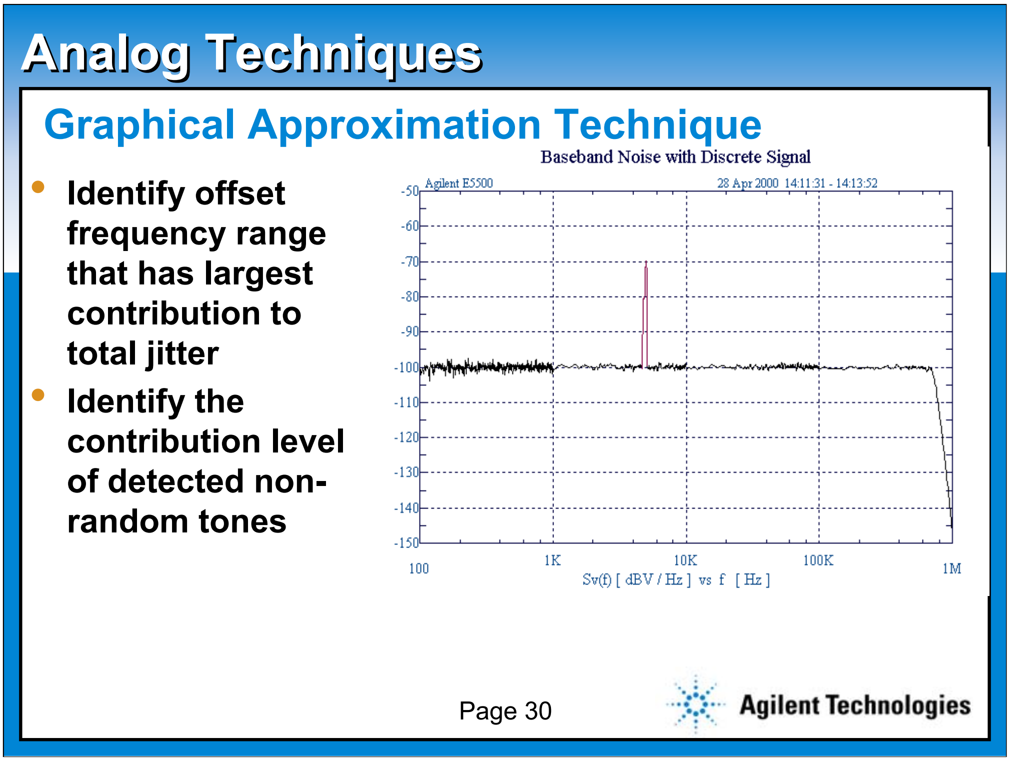


Start(Hz)	Stop(Hz)	rms Phase Jitter
20E+3	80E+6	866E-6 Rad

$$U[\mathrm{ui}] = \frac{\phi[\mathrm{rad}]}{2\pi} = \frac{866\,\mathrm{E}\text{-}6}{2\pi} = 137\mathrm{E}\text{-}6\ \mathrm{UI}$$

Agilent Technologies

The integral of the spectral density of phase fluctuations for this measurements over bandwidth of 20 kHz to 80 MHz yields a value of 866 micro rad (rms) which equates to 137 uUI (rms) of total jitter.



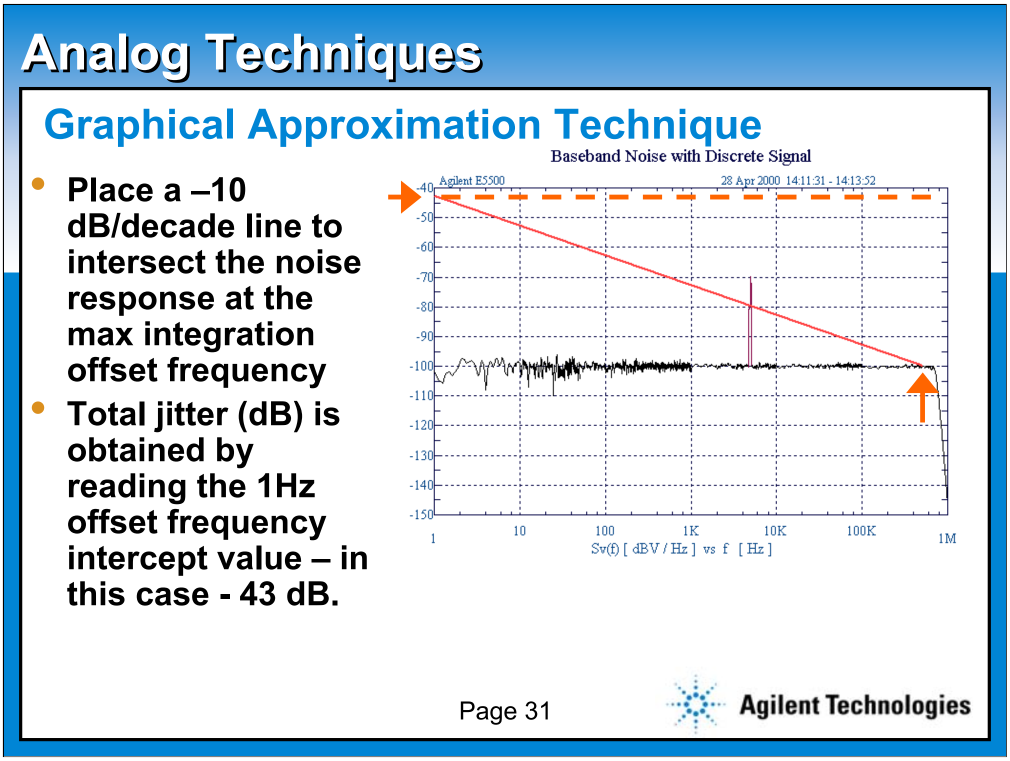
Analog Techniques

Graphical Approximation Technique

- **Identify offset frequency range that has largest contribution to total jitter**
- **Identify the contribution level of detected non-random tones**

Baseband Noise with Discrete Signal

While the mathematical integration process is necessary, there is a way that you can estimate the total integrated noise (in terms of dB) by using a simple graphical technique with the measured phase noise response. The purpose for doing so would be to quickly identify the offset frequency range which has the largest contribution to total jitter, and to evaluate non-random signals as to their contribution to total jitter.



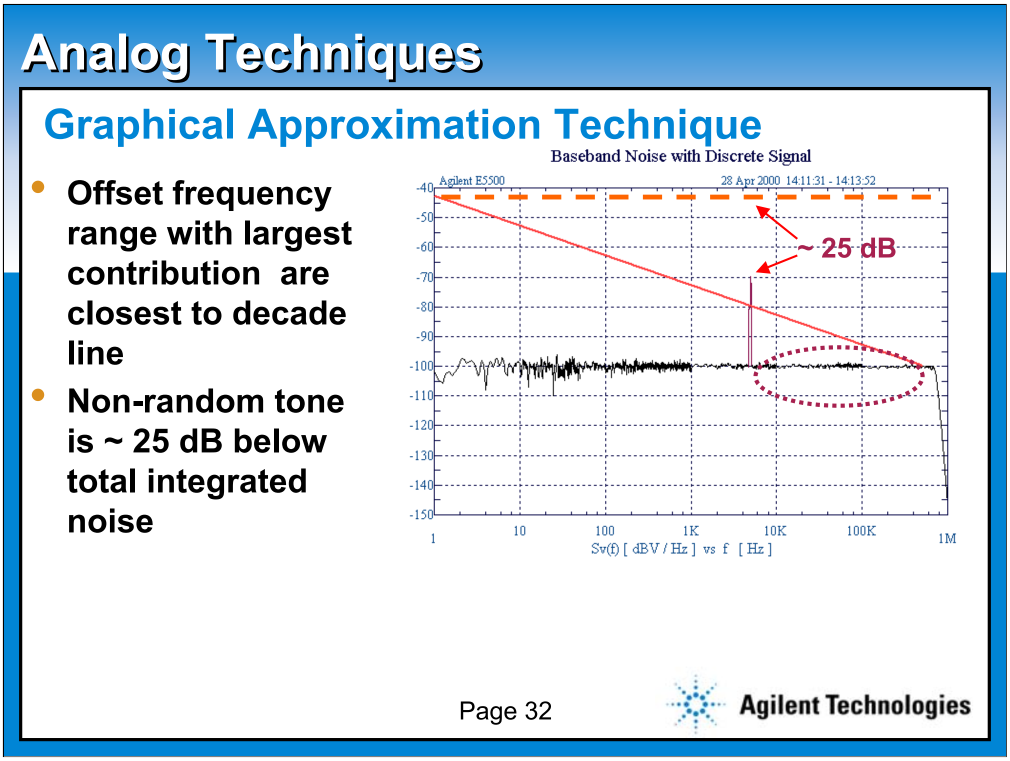
Analog Techniques

Graphical Approximation Technique

- **Place a –10 dB/decade line to intersect the noise response at the max integration offset frequency**
- **Total jitter (dB) is obtained by reading the 1Hz offset frequency intercept value – in this case - 43 dB.**

Agilent Technologies

For broadband noise characteristics, place a –10 dB/decade starting at the maximum offset frequency (for the integration) and using this line to determine the 1 Hz offset intercept value (in this case – 43 dB).



Analog Techniques

Graphical Approximation Technique

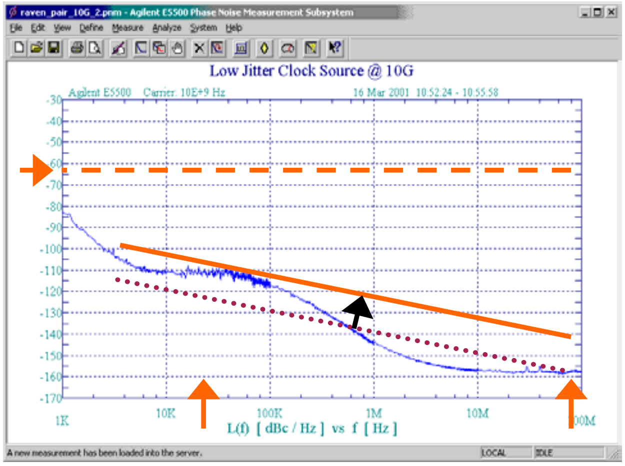
- Offset frequency range with largest contribution are closest to decade line
- Non-random tone is ~ 25 dB below total integrated noise

The two characteristics that the graphical approximation technique presents are 1) the offset frequencies that have the largest contribution to total jitter are those closest to the 10 dB/decade approximation (the horizontal scale is in log frequency and there are more frequencies closer to the decade line than farther away); and 2) the dBc level of the non-random tones with respect to the total integrated noise – in this example the non-random tone is 25 dB below the total integrated noise and has no discernable affect on total jitter.

Analog Techniques

Graphical Approximation Technique

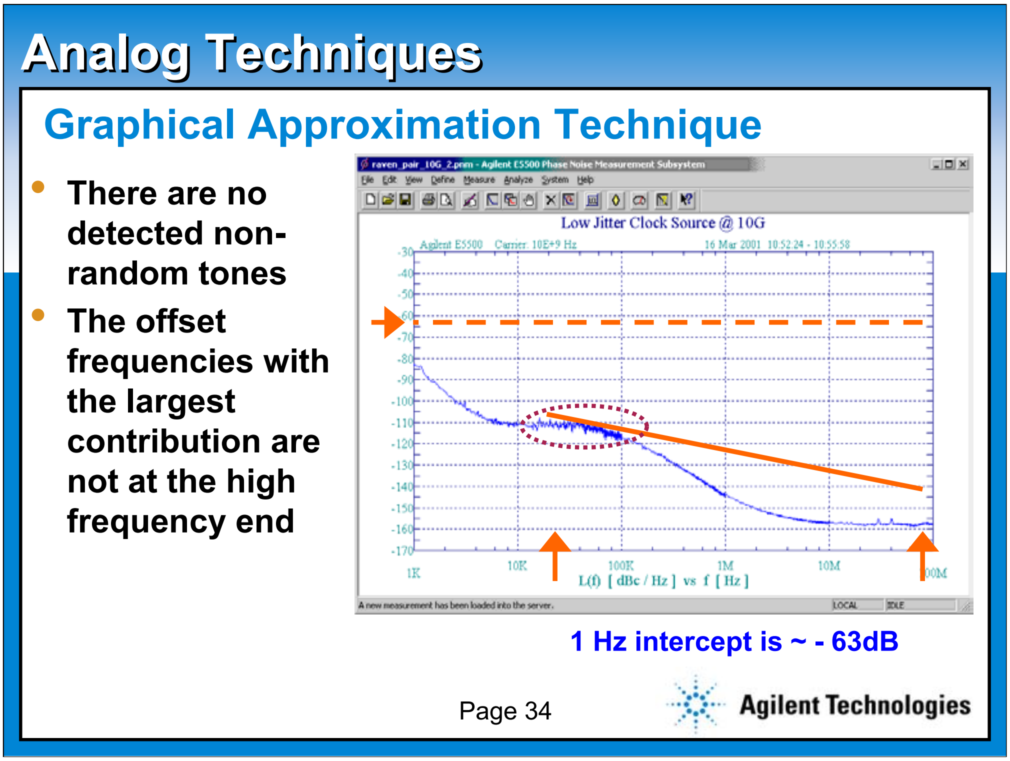
- When the noise response forces the 10dB line to intersect within the integration bandwidth of interest, the line must be raised to where it is tangent to the noise response.



A new measurement has been loaded into the server.

1 Hz intercept is ~ - 63dB

When the DUT noise response causes an unwanted intersection of the 10 dB/decade line within the integration bandwidth of interest, then the 10 dB line must be raised until it is tangent to the highest point in the response (within the integration bandwidth). Total integrated noise is obtained by looking at the 1 Hz offset frequency intercept value.



Analog Techniques

Graphical Approximation Technique

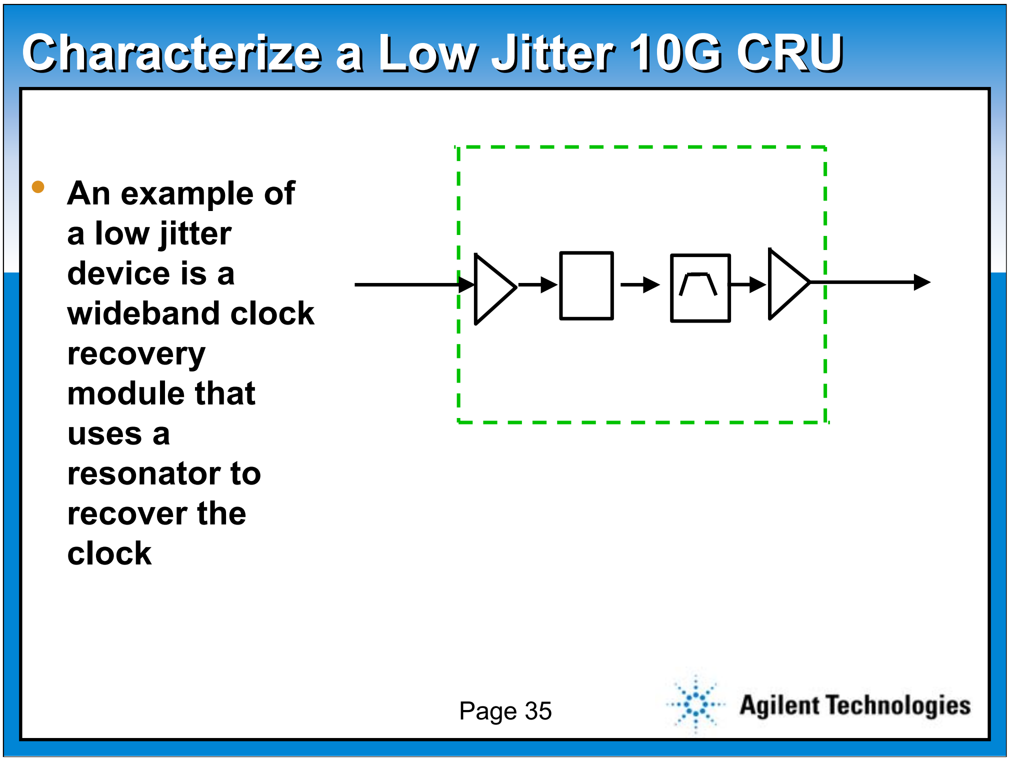
- There are no detected non-random tones
- The offset frequencies with the largest contribution are not at the high frequency end

A new measurement has been loaded into the server.

1 Hz intercept is ~ - 63dB

Agilent Technologies

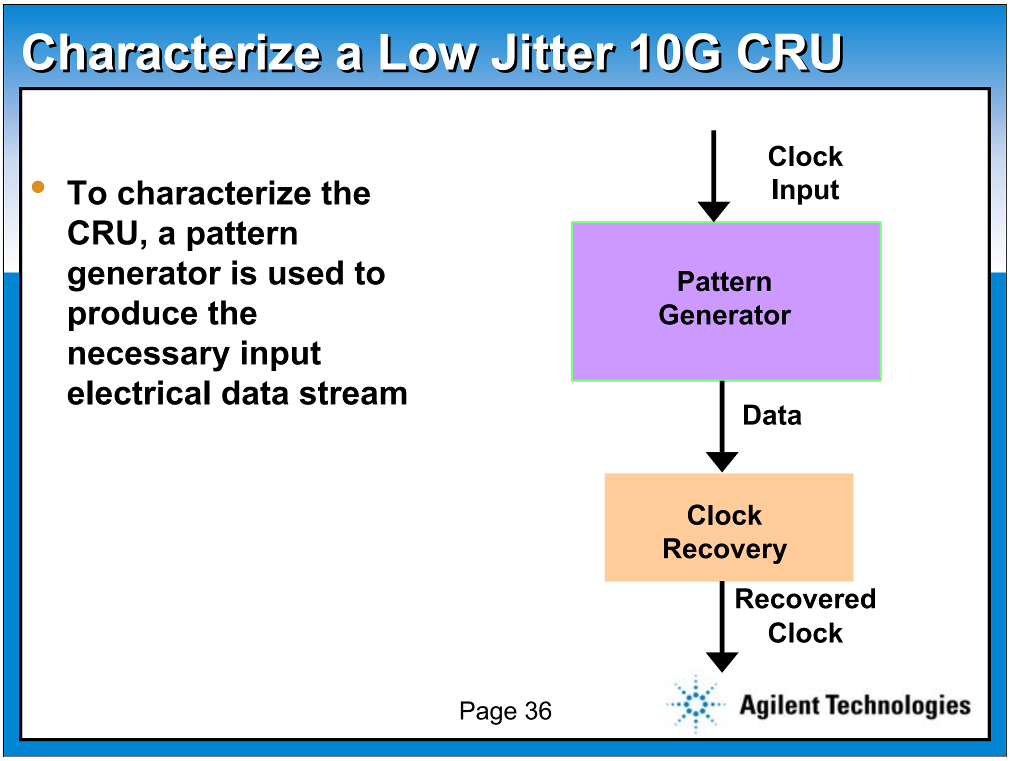
In the case of this DUT, the offset frequencies that have the largest contribution to total jitter are in the 20 kHz to 120 kHz range. This means that if the characteristics of the DUT where to be lowered in this area (and not raised in other areas), then the total jitter would decrease. The total integrated noise is ~ -63 dB.



Characterize a Low Jitter 10G CRU

- An example of a low jitter device is a wideband clock recovery module that uses a resonator to recover the clock

An example of a low jitter device is a wideband clock recovery module that uses a resonator to recover the clock signal from a NRZ data stream. The components of the CRU are mostly active devices that essentially have broadband noise characteristics.



Characterize a Low Jitter 10G CRU

- To characterize the CRU, a pattern generator is used to produce the necessary input electrical data stream

Clock Input

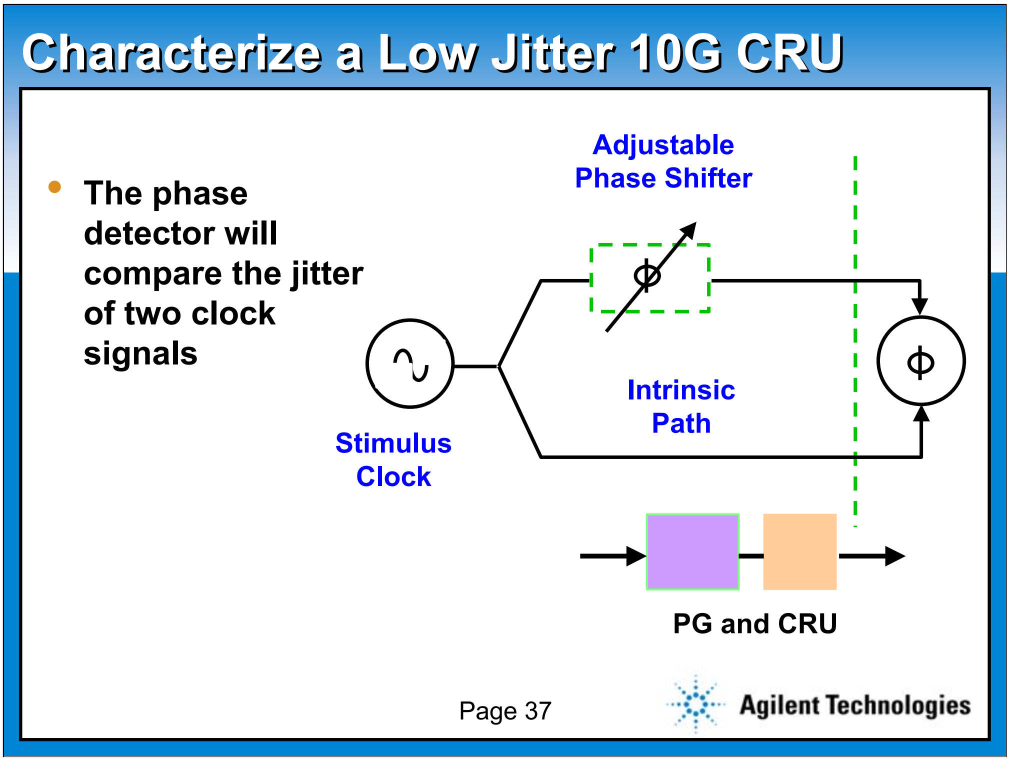
Pattern Generator

Data

Clock Recovery

Recovered Clock

To characterize such a device, it is necessary to apply a serial data stream from a pattern generator. The recovered clock is measured for total jitter.



Characterize a Low Jitter 10G CRU

- The phase detector will compare the jitter of two clock signals

Adjustable Phase Shifter

Intrinsic Path

Stimulus Clock

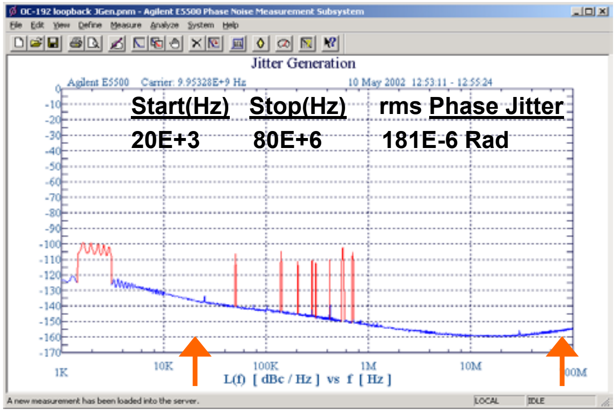
PG and CRU

Agilent Technologies

The lowest noise technique to measure the additive jitter of the CRU is shown here. A stimulus clock is used to provide both signals to the phase detector, with the adjustable phase shifter being used to establish the necessary quadrature conditions. The noise at both inputs is the same and is effectively cancelled out, leaving the intrinsic noise of the phase detector plus the baseband path. To measure the CRU, the pattern generator and CRU combination is inserted into one signal path and quadrature established (the noise of the stimulus clock continues to be cancelled at the phase detector). The measurement result will be that of the PG/CRU combination.

System Intrinsic Jitter

- The measured system intrinsic rms jitter is 28.9 E-6 UI



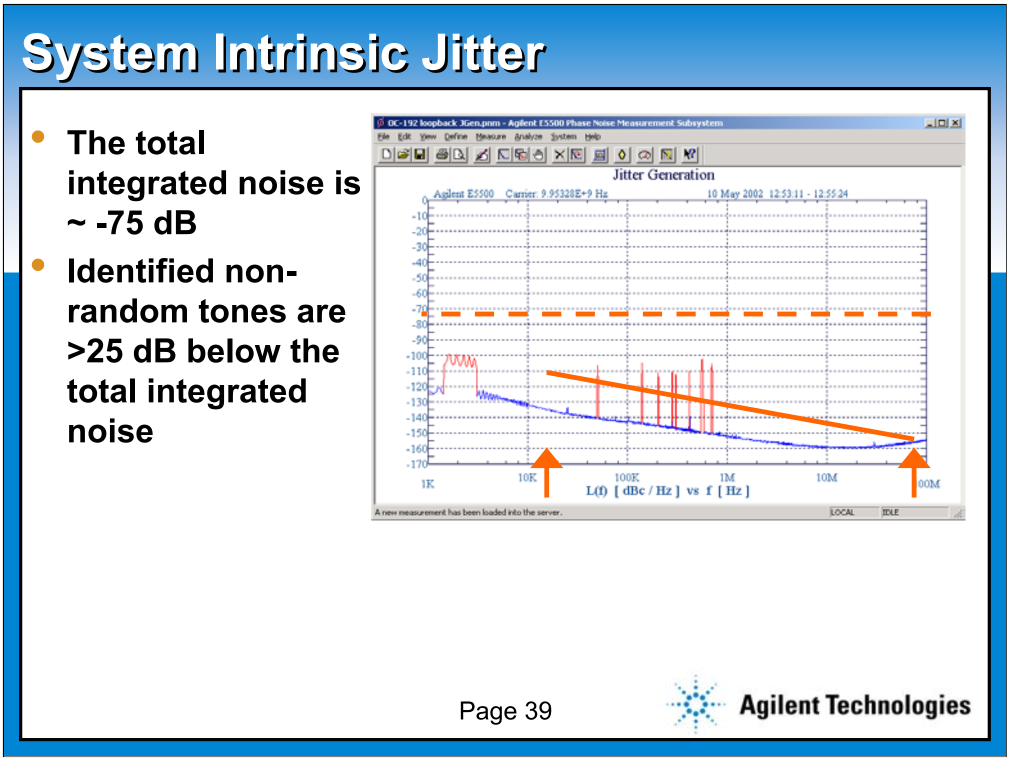
Start(Hz)	Stop(Hz)	rms Phase Jitter
20E+3	80E+6	181E-6 Rad

A new measurement has been loaded into the server.

$$U[\mathrm{ui}] = \frac{\phi[\mathrm{rad}]}{2\pi} = \frac{181\mathrm{E}-6}{2\pi} = 28.9\mathrm{E}-6\ \mathrm{UI}$$

Agilent Technologies

Shown here is the noise characteristics of the intrinsic paths only. The total rms jitter of this configuration is only 42 uUI. This configuration uses the low noise 10 G clock observed early as the stimulus clock. Notice that the system intrinsic jitter is lower than the rms jitter of the clock itself (29 uUI vs 137 uUI).



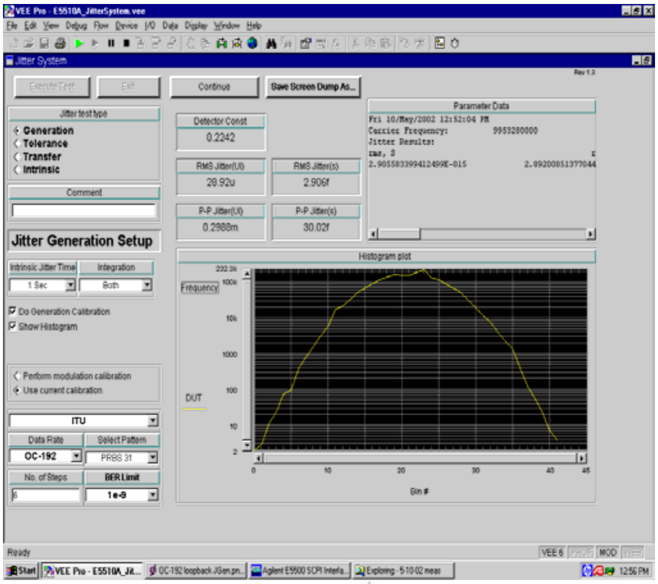
System Intrinsic Jitter

- The total integrated noise is ~ -75 dB
- Identified non-random tones are >25 dB below the total integrated noise

The approximate total integrated noise is –75 dB. The detected non-random tones are > 25 dB below the total integrated noise and have no affect on total jitter.

Peak-to-Peak Jitter Measurement

- The system intrinsic pp measured jitter is 0.2988 mUI and its histogram is Gaussian



● Generation

Detector Const: 0.2242

RMS Jitter(UI): 28.92u

RMS Jitter(s): 2.906f

P-P Jitter(UI): 0.2988m

P-P Jitter(s): 30.02f

Intrinsic Jitter Time: 1 Sec

Integration: Both

☑ Do Generation Calibration

☑ Show Histogram

● Use current calibration

ITU

Data Rate: OC-192

Select Pattern: PRBS 31

No. of Steps: 6

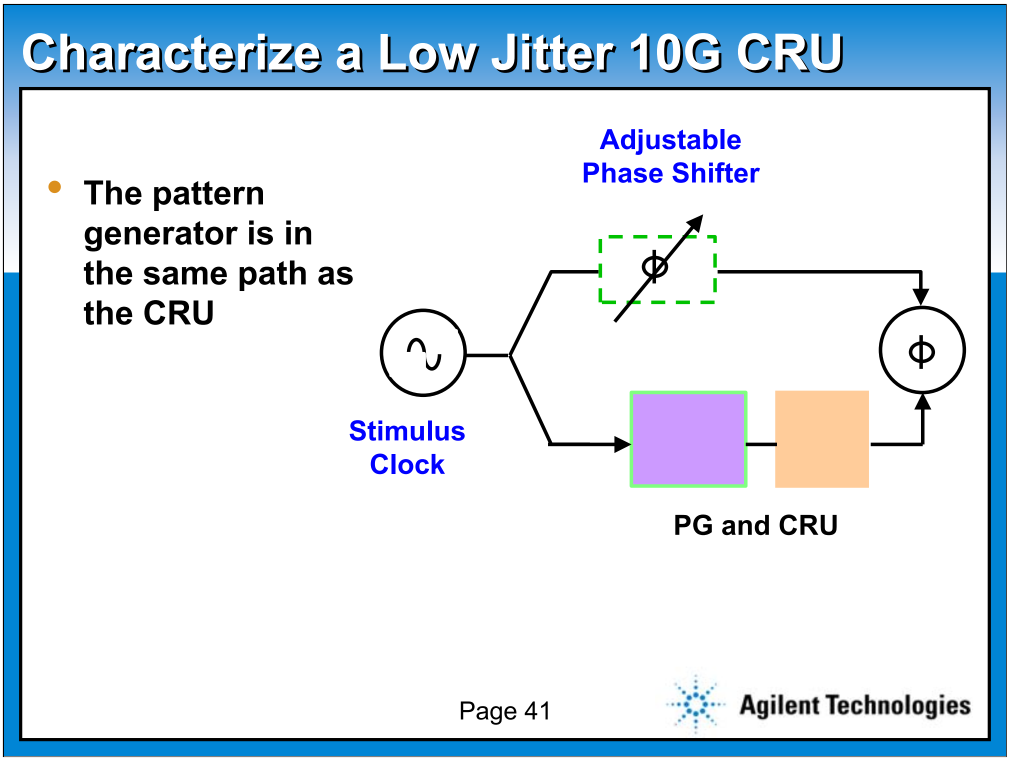
BER Limit: 1e-9

Parameter Data

```
Fri 10/May/2002 12:52:04 PM
Carrier Frequency:          9953280000
Jitter Results:
rms, S                                 r
2.905583399412499E-015          2.89200851377044
```

Agilent Technologies

The histogram characteristics of the measured system intrinsic p-p jitter (0.2988 mUI) is clearly Gaussian in shape (the vertical scale is a log scale of the occurances).



Characterize a Low Jitter 10G CRU

- The pattern generator is in the same path as the CRU

Adjustable Phase Shifter

Φ

Φ

Stimulus Clock

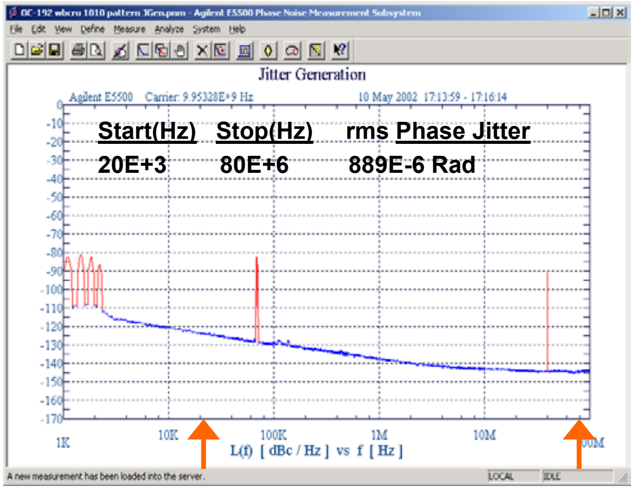
PG and CRU

Agilent Technologies

To measure the CRU, the PG/CRU combination are inserted into one of the signal paths and quadrature established.

Low Jitter Measurement

- A 0101… data pattern used to view total jitter without DDJ
- The PG/CRU measured rms jitter for a 010101… data pattern is 141 E-6 UI



OC-192 wbcru 1010 pattern JGen.pnm - Agilent E5500 Phase Noise Measurement Subsystem

Start(Hz)	Stop(Hz)	rms Phase Jitter
20E+3	80E+6	889E-6 Rad

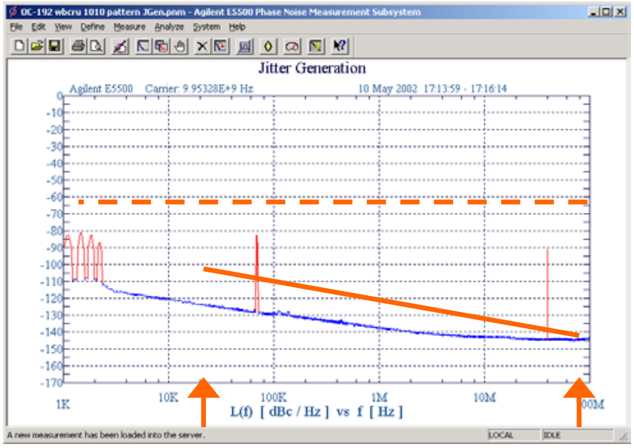
A new measurement has been loaded into the server.

$$U[\mathrm{ui}] = \frac{\phi[\mathrm{rad}]}{2\pi} = \frac{889\,\mathrm{E}\text{-}6}{2\pi} = 141\mathrm{E}\text{-}6\ \mathrm{UI}$$

A 0101…pattern, applied to the CRU, will place any pattern dependent jitter well outside the SONET bandwidth, leaving random jitter as the primary jitter contribution. For this measurement, the total rms jitter for a 0101… pattern is 1417 uUI.

Low Jitter Measurement

- The non-random tone is 20 dB below the total integrated noise
- Offset frequency area with largest contribution is near 80 MHz



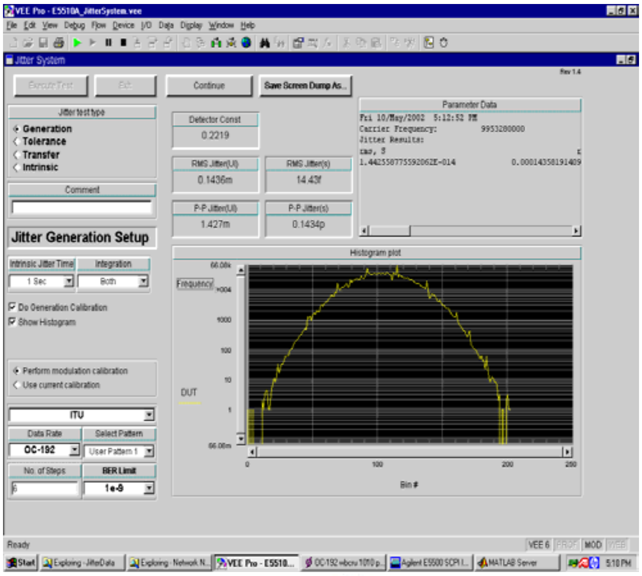
A new measurement has been loaded into the server.

Agilent Technologies

With graphical approximation, the total integrated noise is ~ -65 dB. The non random tone at ~ 80 kHz is ~ -85 dBc which is ~ 20 dB lower than the integrated noise and will have no substantial contribution to total jitter.

Peak-to-Peak Jitter Measurement

- The pp measured jitter for the 0101… data pattern is 1.4 mUI and its histogram is Gaussian



Jitter test type: ● Generation ○ Tolerance ○ Transfer ○ Intrinsic

Detector Const: 0.2219

RMS Jitter(UI): 0.1436m

RMS Jitter(s): 14.43f

P-P Jitter(UI): 1.427m

P-P Jitter(s): 0.1434p

Parameter Data:

```
Fri 10/May/2002  5:12:52 PM
Carrier Frequency:          9953280000
Jitter Results:
rms, S                                          r
1.442558775592062E-014            0.00014358191409
```

Intrinsic Jitter Time: 1 Sec

Integration: Both

☑ Do Generation Calibration

☑ Show Histogram

● Perform modulation calibration

○ Use current calibration

ITU

Data Rate: OC-192

Select Pattern: User Pattern 1

No. of Steps: 6

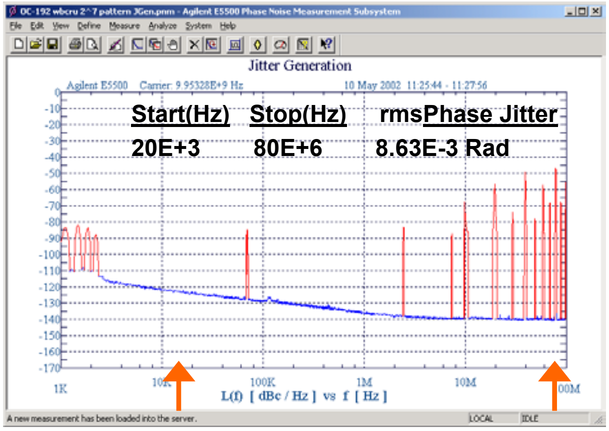
BER Limit: 1e-9

Agilent Technologies

The histogram characteristics of the measured p-p jitter value of 1.4 mUI and is clearly Gaussian in shape (the vertical scale is a log scale of the occurances).

Separating Random Jitter and DDJ

- 2^7-1 PRBS data
- Measured rms jitter for PG/CRU DUT is 1.37 mUI
- The non-random tone at the rep rate of the pattern (78 MHz) dominates the overall rms jitter value



Start(Hz)	Stop(Hz)	rmsPhase Jitter
20E+3	80E+6	8.63E-3 Rad

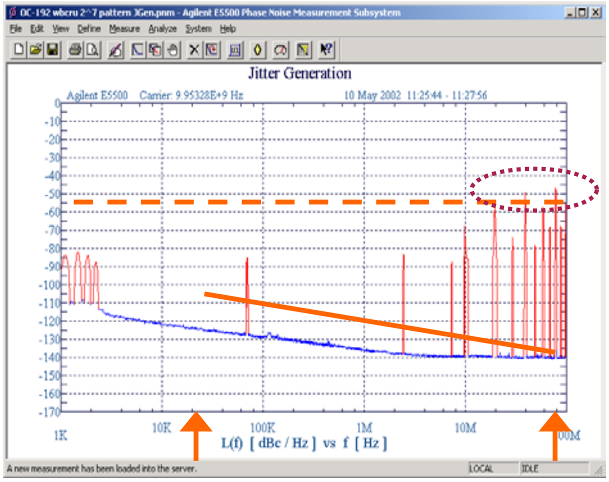
A new measurement has been loaded into the server.

$$U[\mathrm{ui}]=\frac{\phi[\mathrm{rad}]}{2\pi}=\frac{8.63\,\mathrm{E}\text{-}3}{2\pi}=1.37\mathrm{E}\text{-}3\,\mathrm{UI}$$

Applying a 2^7-1 PRBS data pattern to the CRU results with this response. The repetition rate of a 2^7 pattern at 10G is ~ 78 MHz and the detected non-random tones (shown in red > 1 MHz offset from carrier) are related to the data pattern. Random characteristics are shown in blue. The 78 MHz tone is ~ -47 dBc which is ~ 10 dB larger than the total integrated random noise. This tone dominates total jitter.

Separating Random Jitter and DDJ

- Total integrated noise is ~ -57 dB
- Non-random tones exceed the total jitter (dB) approximation

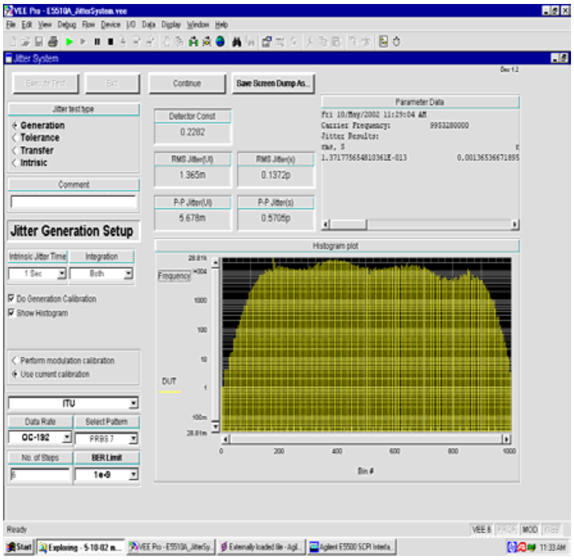


A new measurement has been loaded into the server.

A quick application of the graphical approximation technique shows the the fundamental repetition rate of the data pattern has a magnitude greater than the approximate total integrated noise. Tones which exceed the total integrated noise will dominate the total jitter response.

Peak-to-Peak Jitter Measurement

- The pp measured jitter for the 2^7-1 data pattern is 5.7 mUI and its histogram is non-Gaussian



Jitter test type:
● Generation
○ Tolerance
○ Transfer
○ Intrisic

Detector Const: 0.2282

RMS Jitter(UI): 1.365m

RMS Jitter(s): 0.1372p

P-P Jitter(UI): 5.678m

P-P Jitter(s): 0.5706p

Parameter Data:

```
Fri 10/May/2002 11:29:04 AM
Carrier Frequency:          9953280000
Jitter Results:
rms, S                                          r
1.371775654810361E-013           0.00136536671855
```

Intrinsic Jitter Time: 1 Sec

Integration: Both

☑ Do Generation Calibration
☑ Show Histogram

○ Perform modulation calibration
● Use current calibration

ITU

Data Rate: OC-192

Select Pattern: PRBS 7

No. of Steps: 6

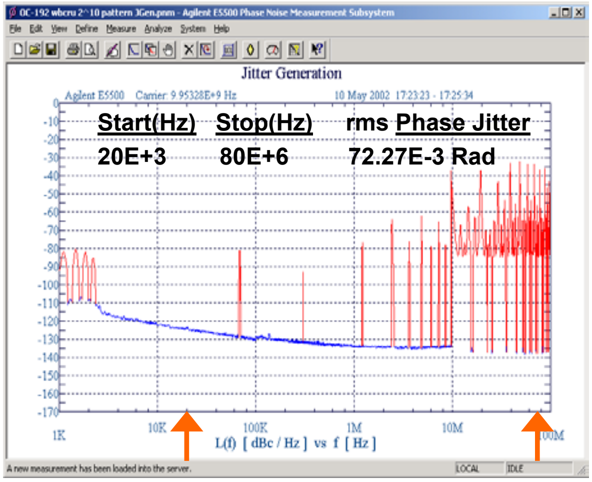
BER Limit: 1e-9

Agilent Technologies

The histogram of the measured p-p jitter is shown here and is clearly not Gaussian.

Separating Random Jitter and DDJ

- **The measured rms jitter for a 2^{10}-1 data pattern is 11.5 E-3 UI**



Start(Hz)	Stop(Hz)	rms Phase Jitter
20E+3	80E+6	72.27E-3 Rad

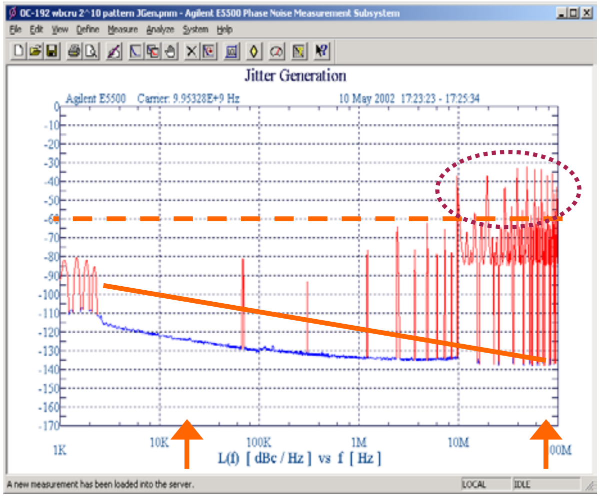
A new measurement has been loaded into the server.

$$U[\mathrm{ui}] = \frac{\phi[\mathrm{rad}]}{2\pi} = \frac{72.27\,\mathrm{E}\text{-}3}{2\pi} = 11.5\mathrm{E}\text{-}3\ \mathrm{UI}$$

Increasing the pattern length to 2^10-1 shows more pattern related tones. The level of the tones are dominating the overall rms jitter measurement.

Separating Random Jitter and DDJ

- The total integrated noise is ~ -60 dB
- More pattern related tones that exceed the total integrated noise value

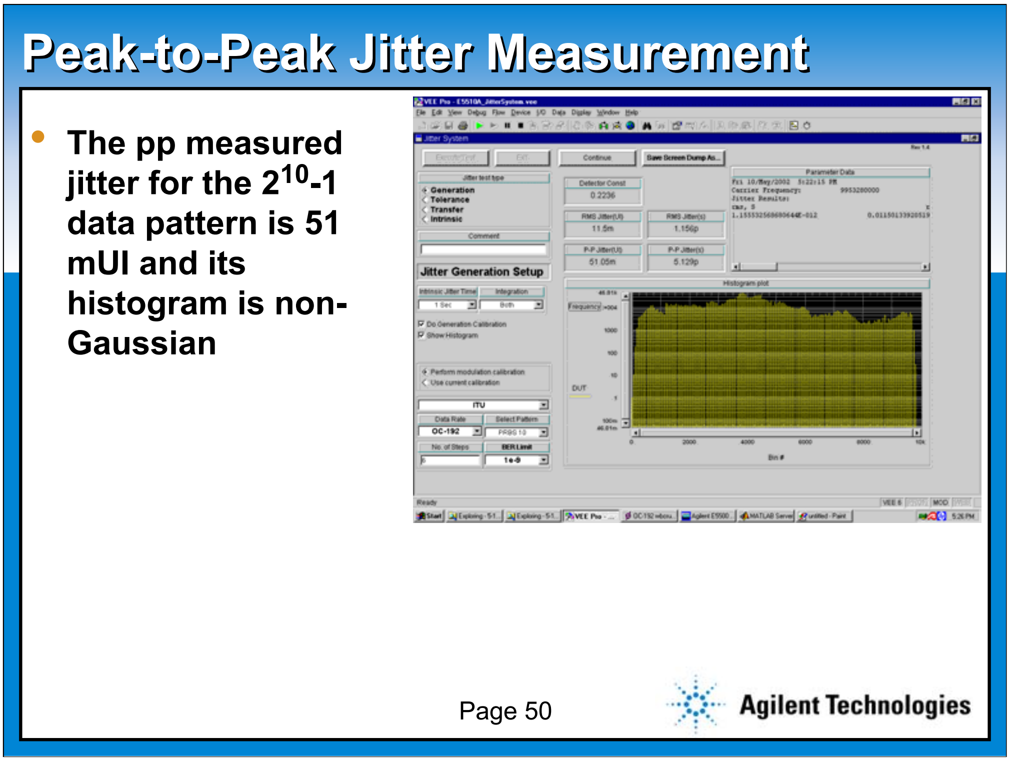


OC-192 wbcru 2^10 pattern JGen.pnm - Agilent E5500 Phase Noise Measurement Subsystem

A new measurement has been loaded into the server.

Agilent Technologies

As we can see here, there are more tones than the previous 2^7 pattern that exceed the total integrated noise level.



Peak-to-Peak Jitter Measurement

- The pp measured jitter for the 2^{10}-1 data pattern is 51 mUI and its histogram is non-Gaussian

Jitter test type
● Generation
○ Tolerance
○ Transfer
○ Intrinsic

Comment

Detector Const: 0.2236

RMS Jitter(UI): 11.5m

RMS Jitter(s): 1.156p

P-P Jitter(UI): 51.05m

P-P Jitter(s): 5.129p

Parameter Data
Fri 10/May/2002 5:22:15 PM
Carrier Frequency: 9953280000
Jitter Results:
rms, S
1.15553256868064 4E-012 0.011501339205 19

Jitter Generation Setup

Intrinsic Jitter Time: 1 Sec

Integration: Both

☑ Do Generation Calibration
☑ Show Histogram

● Perform modulation calibration
○ Use current calibration

ITU

Data Rate: OC-192

Select Pattern: PRBS 10

No. of Steps: 5

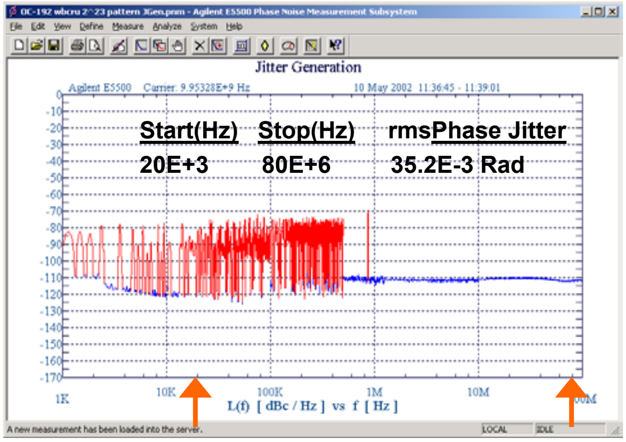
BER Limit: 1e-9

Agilent Technologies

It is not surprising that the pp jitter measurement of total jitter has leaped to 51 mUI.

Separating Random Jitter and DDJ

- The measured rms jitter for the PG/CRU with a 2^{23}-1 data pattern is 5.6 E-3 UI
- Pattern related tones for frequency offsets > 500 kHz are not resolved



Start(Hz)	Stop(Hz)	rmsPhase Jitter
20E+3	80E+6	35.2E-3 Rad

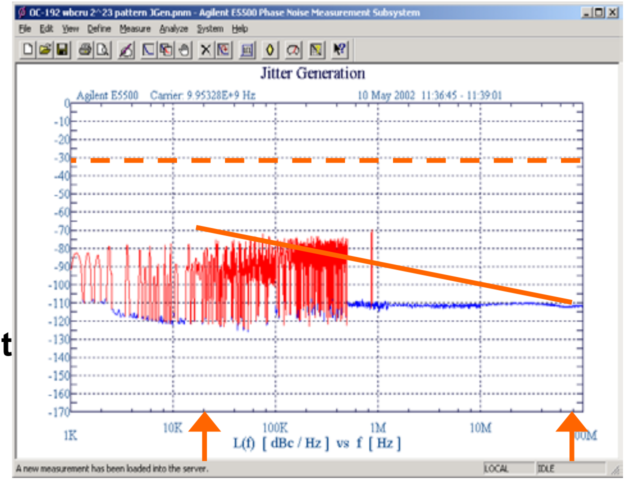
$$U[\mathrm{ui}] = \frac{\phi[\mathrm{rad}]}{2\pi} = \frac{35.4\mathrm{E}\text{-}3}{2\pi} = 5.6\mathrm{E}\text{-}3\ \mathrm{UI}$$

Agilent Technologies

As the PRBS data pattern gets longer, the repetition rate in frequency gets smaller. For 2^23-1 pattern, the total rms jitter is 5.6 mUI, considerably larger than the shorter data patterns. The repetition rate of the pattern is ~ 1.2 kHz and pattern related tones > 500 kHz offset from the carrier are not resolved and appear as noise (random).

Separating Random Jitter and DDJ

- The approximate total noise is –30 dB
- The harmonics of the data pattern (~1.2 kHz rep rate) are too closely spaced and are not resolved



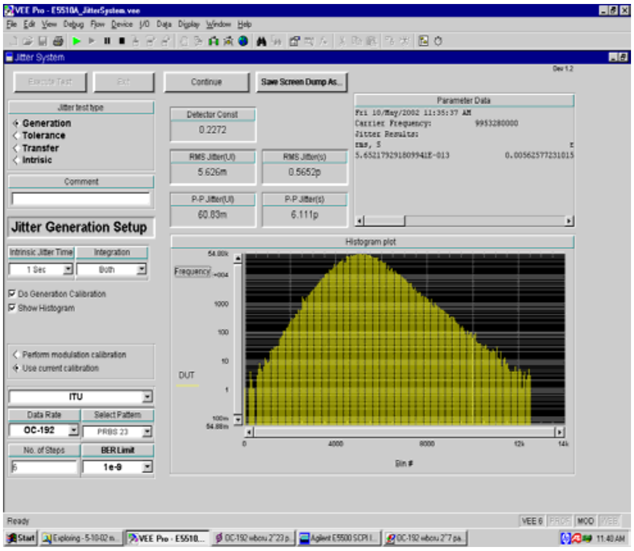
A new measurement has been loaded into the server.

Agilent Technologies

A quick application of the graphical approximation technique yields a total integrated noise of ~ -30 dB.

Peak-to-Peak Jitter Measurement

- **The pp measured jitter for the 2^{23}-1 data pattern is 60.8 mUI and its histogram looks partially random**



Jitter test type: ● Generation ○ Tolerance ○ Transfer ○ Intrisic

Comment:

Detector Const: 0.2272

RMS Jitter(UI): 5.626m

RMS Jitter(s): 0.5652p

P-P Jitter(UI): 60.83m

P-P Jitter(s): 6.111p

Parameter Data:

```
Fri 10/May/2002 11:35:37 AM
Carrier Frequency:          9953280000
Jitter Results:
rms, S                                                   r
5.65217929180994lE-013              0.00562577231015
```

Intrinsic Jitter Time: 1 Sec

Integration: Both

☑ Do Generation Calibration

☑ Show Histogram

○ Perform modulation calibration

● Use current calibration

ITU

Data Rate: OC-192

Select Pattern: PRBS 23

No. of Steps: 6

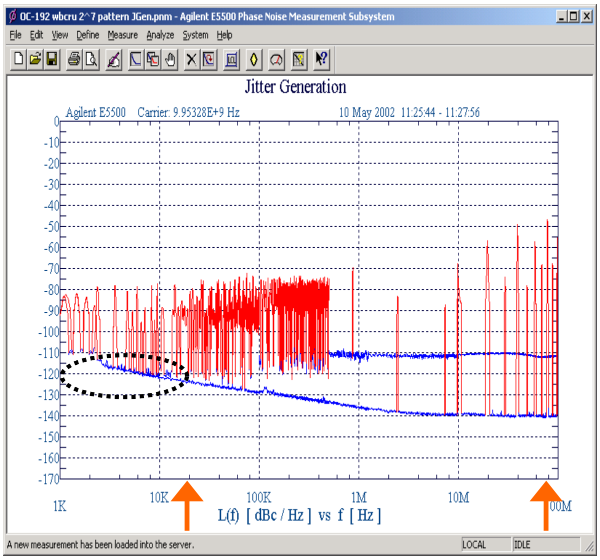
BER Limit: 1e-9

The histogram for the pp measurement actually looks random (starting to approach Gaussian). It appears that PRBS related tones for long data patterns that are measured with a relatively narrow bandwidth look like noise, even this effective noise is "data dependent".

Notice that the pp value has risen only modestly from the 2^10 pattern while the rms value is actually smaller than the 2^10 rms value.

Comparing 2^{23} and 2^7 Results

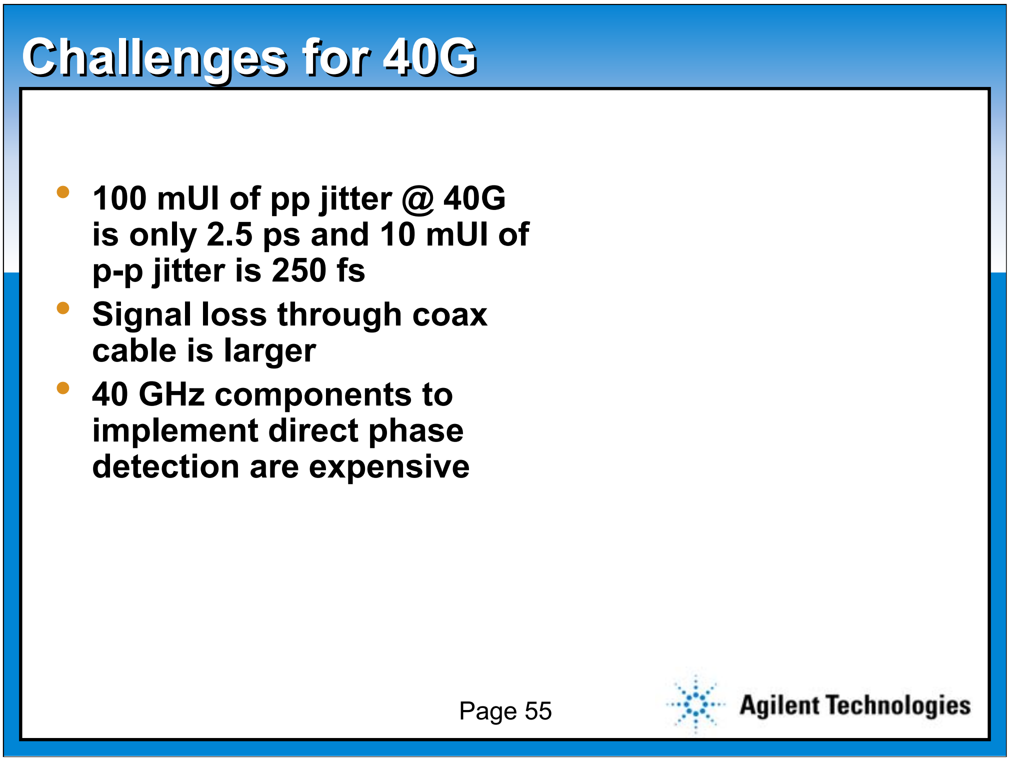
- “Noise” appears to have increased by 30 dB!
- The random noise in the 1 kHz – 10 kHz offset range are the same!
- Increased “noise” is discrete pattern jitter that will appear as “random” in the total pp jitter measurement



OC-192 wbcru 2^7 pattern JGen.pnm - Agilent E5500 Phase Noise Measurement Subsystem

A new measurement has been loaded into the server.

If we compare a 2^23 data pattern result with a 2^7 data pattern result, we can see that the non-data-dependent noise (shown here within the indicated circle) is the same for both patterns. The many unresolved tones far from carrier is what causes the increase of “noise” for the 2^23 pattern (as compared to the 2^7 pattern).



Challenges for 40G

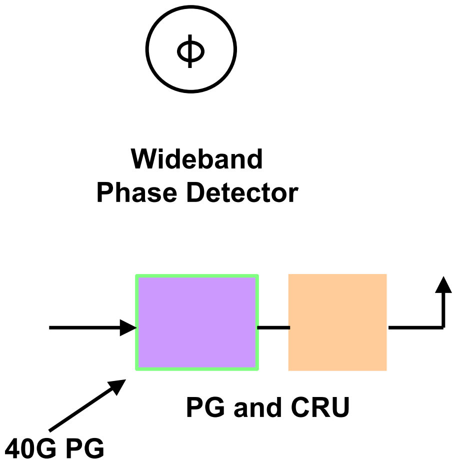
- 100 mUI of pp jitter @ 40G is only 2.5 ps and 10 mUI of p-p jitter is 250 fs
- Signal loss through coax cable is larger
- 40 GHz components to implement direct phase detection are expensive

Agilent Technologies

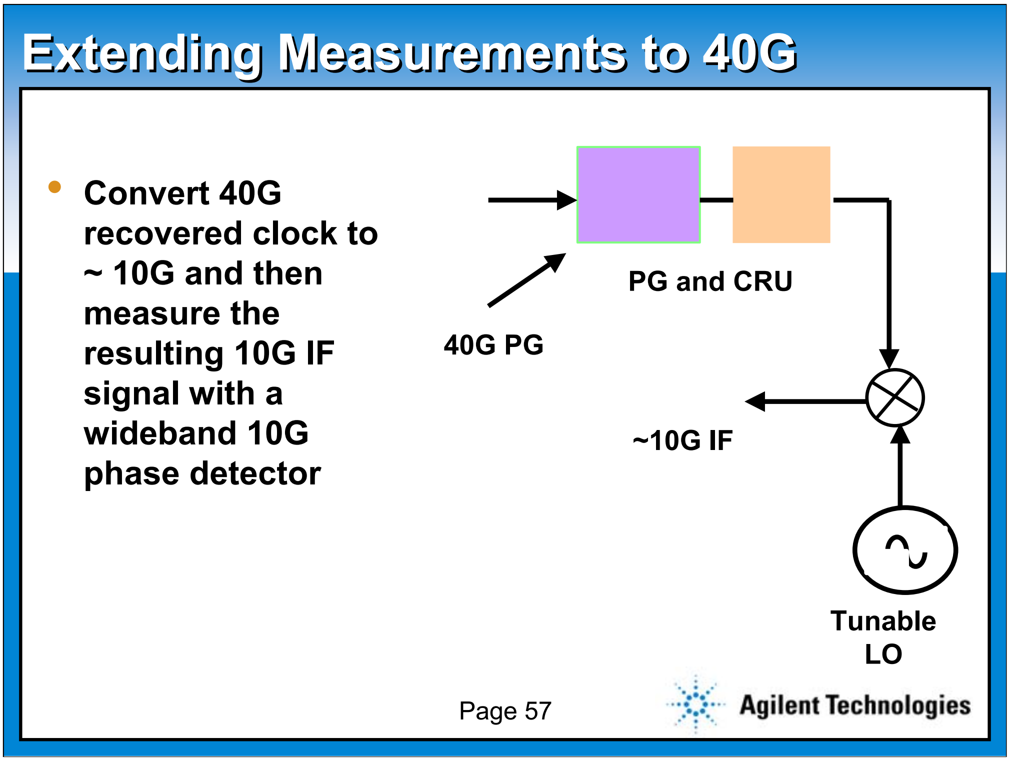
At 40G data rates, achieving low jitter is even more challenging. At 40G, 100 mUI of jitter of 2.4 ps is 1/4 that at 10G. Signal losses through coax cable is larger at 40G, and certainly to implement direct phase detection at 40 G, when 40G components are used, will result in a very expensive solution.

Extending Measurements to 40G

- **Minimize cost**
- **Maximize performance**
- **Wideband phase detector**
- **40G pattern generator**



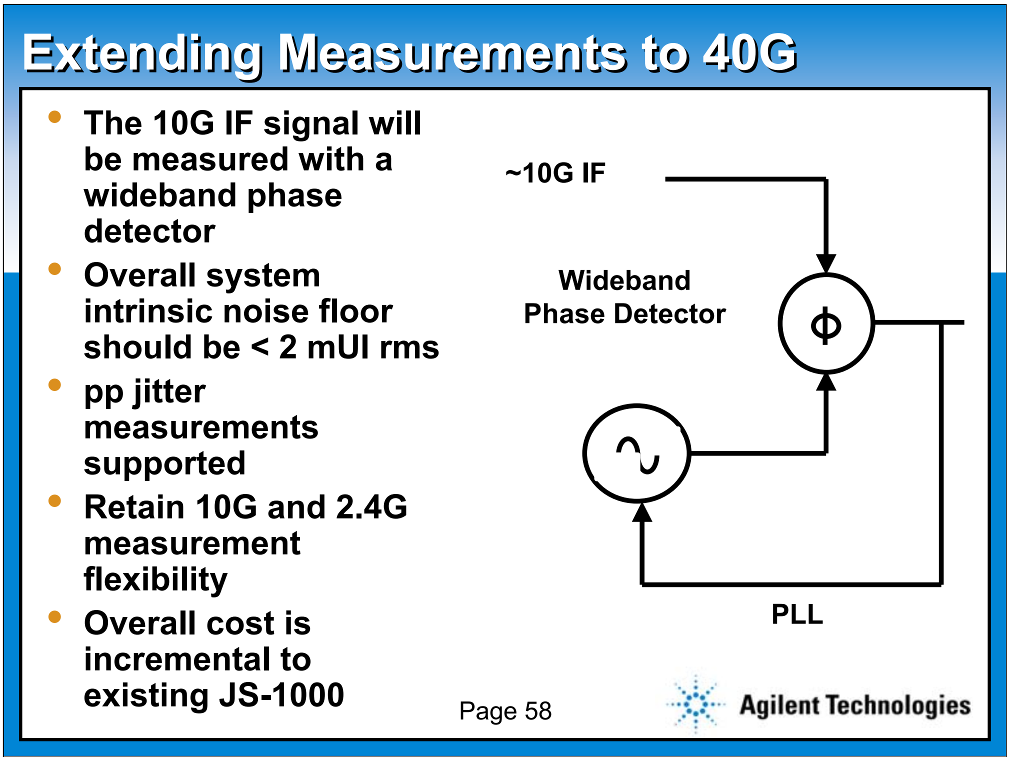
For the frequency domain approach, the goal is to extend the phase detector approach while minimizing the overall cost. Required elements at 40G include a wideband phase detector (up to 320 MHz of baseband bandwidth) and a 40G pattern generator.



Extending Measurements to 40G

- Convert 40G recovered clock to ~ 10G and then measure the resulting 10G IF signal with a wideband 10G phase detector

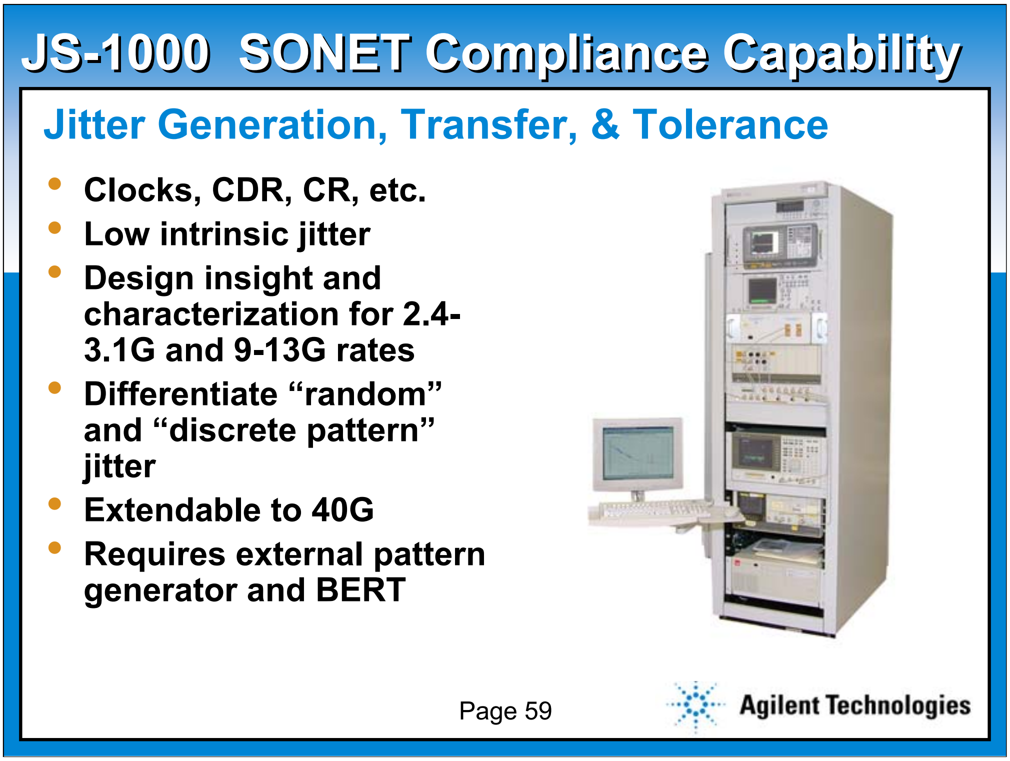
Assuming that a 40G pattern generator is in place, the recovered clock (DUT) can be mixed down to an ~ 10GHz IF signal by using a low noise mixer and a low noise tuneable LO.



Extending Measurements to 40G

- The 10G IF signal will be measured with a wideband phase detector
- Overall system intrinsic noise floor should be < 2 mUI rms
- pp jitter measurements supported
- Retain 10G and 2.4G measurement flexibility
- Overall cost is incremental to existing JS-1000

The wideband phase detector is being implemented at ~ 10G to minimize costs down while keeping the performance high. In this approach, the overall system intrinsic jitter is expected to be < 2 mUI rms (.05 ps rms) for the expected SONET bandwidth of 320 MHz. The resulting 40G configuration will be incremental to that of a 10G solution while retaining the flexibility to measure 10G (and 2.4G) components.

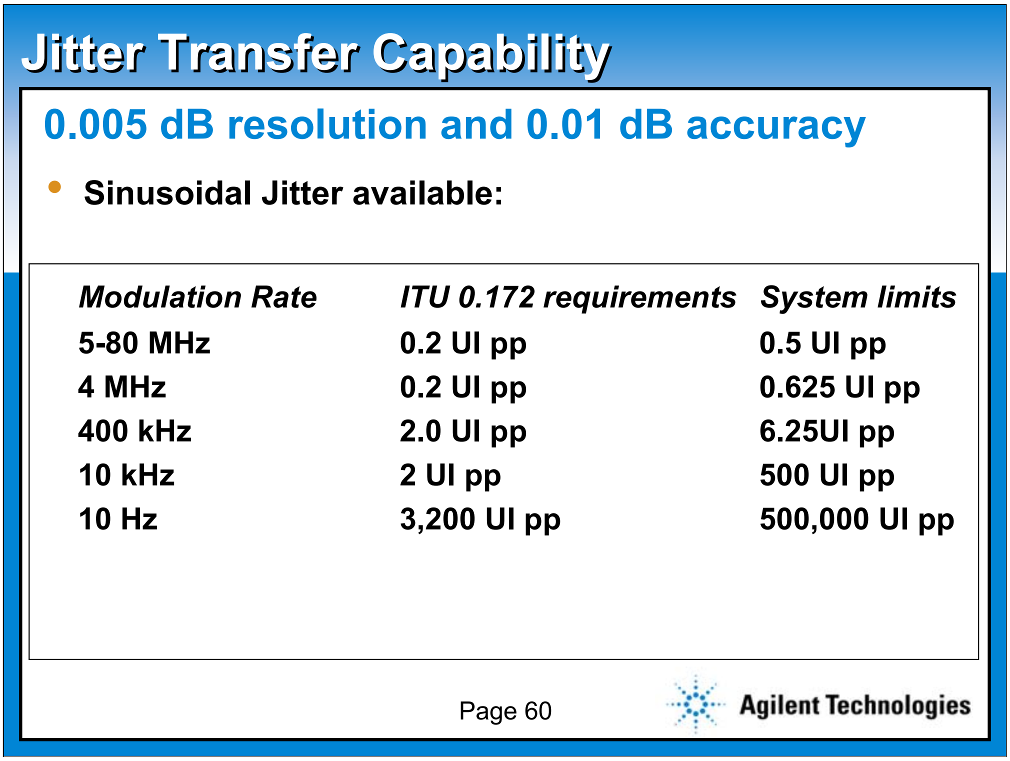


JS-1000 SONET Compliance Capability

Jitter Generation, Transfer, & Tolerance

- Clocks, CDR, CR, etc.
- Low intrinsic jitter
- Design insight and characterization for 2.4-3.1G and 9-13G rates
- Differentiate “random” and “discrete pattern” jitter
- Extendable to 40G
- Requires external pattern generator and BERT

The analog techniques we have been discussing are implemented within Agilent’s JS-1000 jitter measurement solution. In addition to measuring low levels of jitter (jitter generation) for SONET clock rates of 2.4-3.1G and 9-13G , the JS-1000 also provides a compliant measurement solution for jitter transfer and tolerance. All of these measurements require an external pattern generator and jitter tolerance requires an external error detector. Lastly, the JS-1000 10G solution is extendable to 40G.



Jitter Transfer Capability

0.005 dB resolution and 0.01 dB accuracy

- **Sinusoidal Jitter available:**

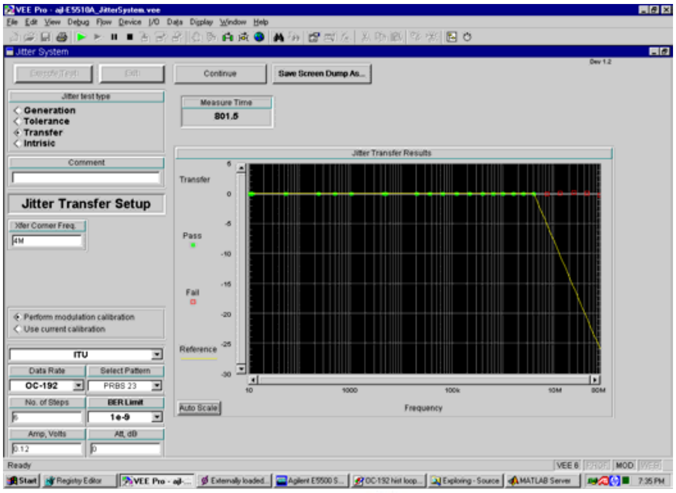
Modulation Rate	*ITU 0.172 requirements*	*System limits*
5-80 MHz	0.2 UI pp	0.5 UI pp
4 MHz	0.2 UI pp	0.625 UI pp
400 kHz	2.0 UI pp	6.25UI pp
10 kHz	2 UI pp	500 UI pp
10 Hz	3,200 UI pp	500,000 UI pp

Jitter transfer and tolerance SONET/SDH measurements require intentional sinusoidal jitter be applied. The JS-1000 exceeds the intentional jitter requirements allowing stress testing of devices during development.

JS-1000 SONET Compliance Capability

Jitter Transfer & Tolerance Performance

- **Jitter Transfer**



Jitter test type
○ Generation
○ Tolerance
● Transfer
○ Intrisic

Comment

Measure Time
801.5

Jitter Transfer Setup

Xfer Corner Freq.
4M

● Perform modulation calibration
○ Use current calibration

ITU

Data Rate: OC-192
Select Pattern: PRBS 23
No. of Steps: 6
BER Limit: 1e-9
Amp, Volts: 0.12
Att, dB: 0

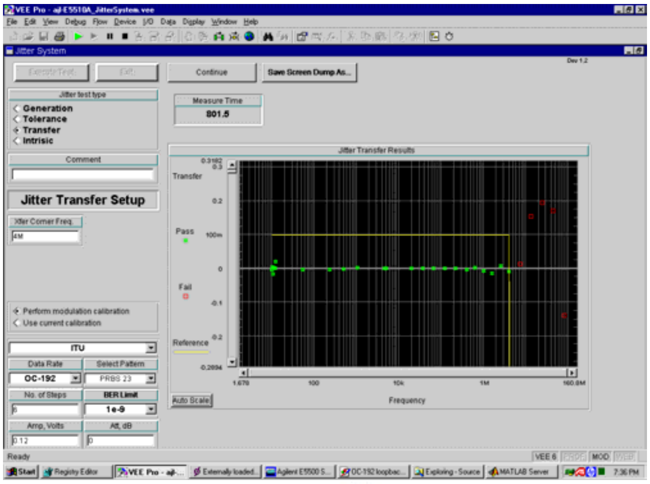
Agilent Technologies

Shown here is a typical 10G jitter transfer result at full scale. It is difficult to observe the peaking at this scale.

JS-1000 SONET Compliance Capability

Jitter Transfer & Tolerance Performance

- High resolution Jitter Transfer



Jitter test type
○ Generation
○ Tolerance
● Transfer
○ Intrisic

Comment

Jitter Transfer Setup

Xfer Corner Freq.: 4M

Measure Time: 801.5

● Perform modulation calibration
○ Use current calibration

ITU

Data Rate	Select Pattern
OC-192	PRBS 23

No. of Steps	BER Limit
6	1e-9

Amp, Volts	Att, dB
0.12	0

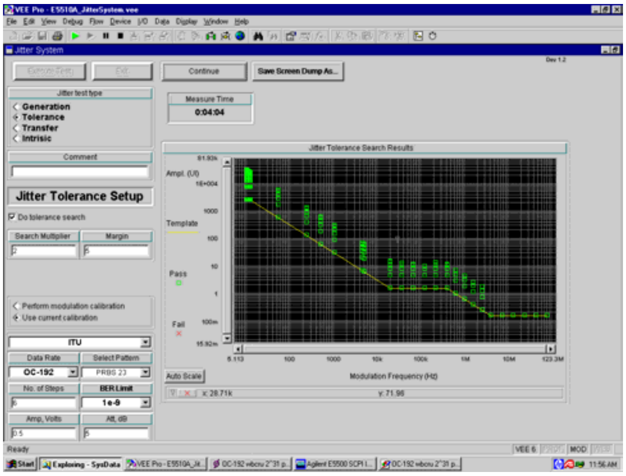
Agilent Technologies

Jitter transfer can also be observed in high resolution mode where it is easy to see small variation in the results. The JS-1000 has 0.005 dB of resolution and 0.01 dB of accuracy up to 10 MHz of applied jitter modulation.

JS-1000 SONET Compliance Capability

Jitter Transfer & Tolerance Performance

- **Jitter Tolerance**



Jitter test type: ○ Generation ● Tolerance ○ Transfer ○ Intrisic

Measure Time: 0:04:04

Comment:

Jitter Tolerance Setup

☑ Do tolerance search

Search Multiplier: 2

Margin: 5

● Use current calibration

ITU

Data Rate: OC-192

Select Pattern: PRBS 23

No. of Steps: 6

BER Limit: 1e-9

Amp, Volts: 0.5

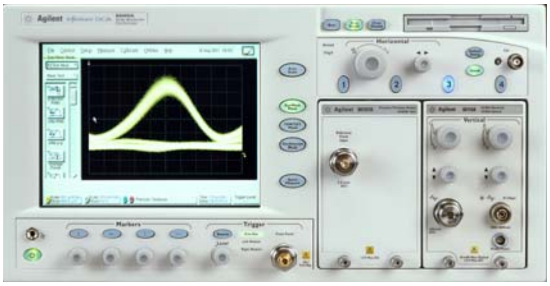
Att, dB: 6

x: 28.71k y: 71.96

A typical 10G jitter tolerance output where stress levels of sinusoidal beyond compliance have been applied.

Time-domain Waveform Analysis

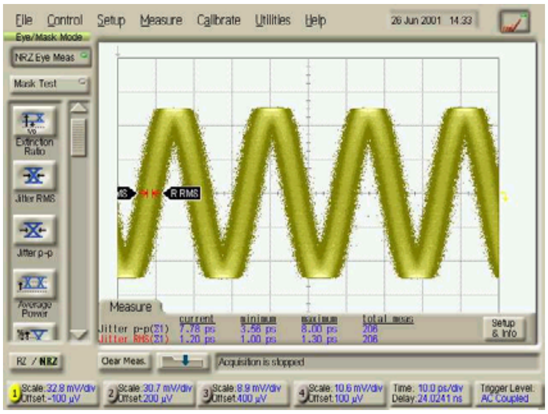
- **Waveform analysis in the time-domain is also problematic at 40G**



Looking at a low noise 40G clock signal in the time domain using a typical wide-bandwidth oscilloscope (one with ~ 1 ps of rms jitter) will result in significant eye closure if the typical scope timing is not improved.

Typical Time-domain Waveform Analysis

- Typical wideband has ~ 1 ps rms jitter (6 ps pp)
  - This results in noticeable eye closure at 40 Gb/s
- Cause is not maintaining time precision from trigger event to sampling instant



Measure

	current	minimum	maximum	total meas
Jitter p-p(Σ1)	7.78 ps	3.56 ps	8.00 ps	206
Jitter RMS(Σ1)	1.20 ps	1.00 ps	1.30 ps	206

Acquisition is stopped

1 Scale: 32.8 mV/div Offset: -100 µV

2 Scale: 30.7 mV/div Offset: 200 µV

3 Scale: 8.9 mV/div Offset: 400 µV

4 Scale: 10.6 mV/div Offset: 100 µV

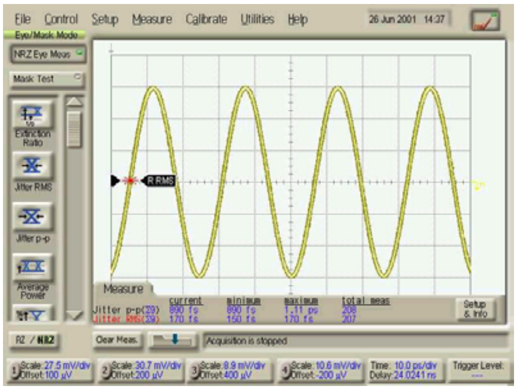
Time: 10.0 ps/div Delay: 24.0241 ns

Trigger Level: AC Coupled

An example of measuring a 40 G clock signal with a typical wideband oscilloscope is shown here. Notice that the rms jitter is ~ 1 ps rms and 6 ps pp.

Waveform Analysis with improved timing

- Improved triggering and precision yields 170 fs rms (6.8 mUI rms) jitter
  - See low jitter signals cleanly



	current	minimum	maximum	total meas
Jitter p-p(29)	890 fs	890 fs	1.11 ps	208
Jitter RMS(29)	170 fs	150 fs	170 fs	207

Acquisition is stopped

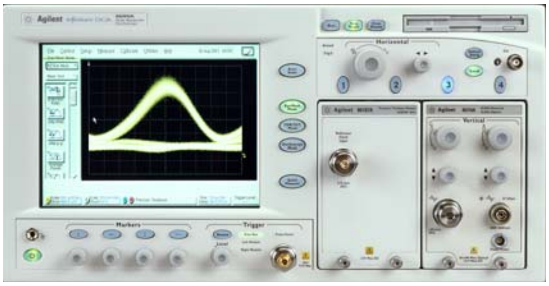
1 Scale: 27.5 mV/div Offset: 100 µV
2 Scale: 30.7 mV/div Offset: 200 µV
3 Scale: 8.9 mV/div Offset: 400 µV
4 Scale: 10.6 mV/div Offset: -200 µV
Time: 10.0 ps/div Delay: 24.0241 ns
Trigger Level: ---

By applying an improved triggering/time reference to the scope, the intrinsic jitter of the scope can be reduced significantly allowing a more clear view of a low jitter signal. 0.17 ps of rms jitter at 40G is equal to 6.8 mUI rms jitter.

Improved Time Domain Analysis

Agilent 86100B DCA

- 86107A - improved precision time reference module
- Time domain waveform analysis to 40 G
- Eye diagrams
- Direct measurement of broadband jitter (rms and pp)
- Available now



Agilent Technologies

The Agilent 86100B DCA family with its 86107A improved precision time reference module provides the low time domain intrinsic jitter for direct time-domain wave form and eye diagram analysis.

Conclusions

- **Measurements of low jitter devices require measurement systems with low intrinsic jitter**
- **Differentiating random jitter from discrete components in the frequency domain speeds design improvement**
- **High performance analog techniques can be applied to 40G devices**

- **Jitter Solutions:** ***www.agilent.com/find/jitter***

Agilent Technologies

In conclusion:

1) **the characterization of low jitter devices require solutions that have low intrinsic jitter.**

2) **Information gathered and displayed in the frequency domain, such as differentiating random jitter from discrete data related tones, speeds overall design improvements;**

3) **High performance analog techniques that are successful at 10G can be extended and applied to 40G device measurements.**