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T10/08-121r0
Limitations of df/dt Specification for SSC Profiles

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Overview

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- JTF Residual Jitter vs SSC Profile df/dt (No HF Content)
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- Improving the Slope Measurement With Low-Pass Filtering
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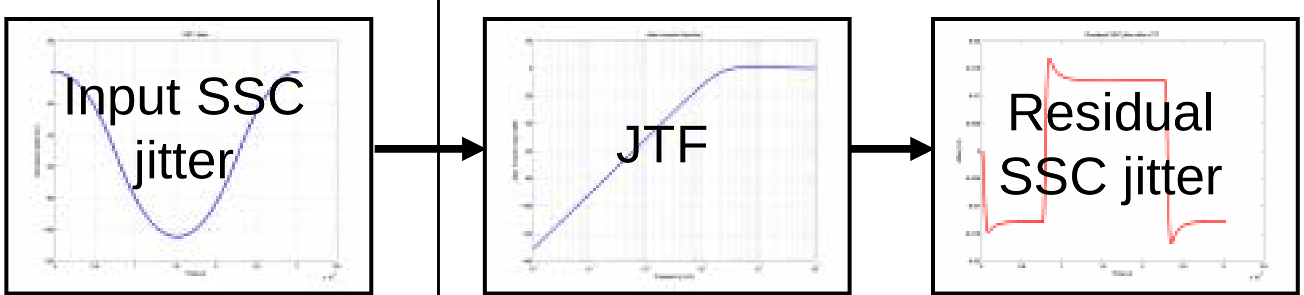
Previous material

- A proposal for JTF-based and df/dt-based specifications of the SSC profiles was developped in previous material:
  - 08-027r3: “Toward SSC Modulation Specs and Link Budget”
  - 08-032r4: “Proposed modifications to SSC profile definition “
- This proposal was included into sas2r14.

Revised Simulation Methodology

- Created various SSC frequency modulation and jitter profiles
- SSC profiles are created directly for a 6Gb/s 1010 pattern
  - SSC jitter is not filtered through a PLL as in 08-027, which allows for the addition of high frequency jitter.
- Residual jitter is obtained by passing SSC jitter through JTF



Transmitter

Receiver

Limitations of Previous Proposals

- 08-027r3 and 08-032r4 established a proportional relationship between the SSC slope and the residual jitter after the JTF
- This presentation shows that the relationship between the SSC slope and the JTF filtered jitter holds only for low frequency content.

Value of Residual Jitter From SSC Slope (1)

Derivation of Final Jitter Caused by a Frequency Ramp

- Final value of the residual jitter when the jitter produced by a frequency ramp is filtered by the JTF

$$\lim_{t\to\infty} Jitter(t) = \lim_{s\to 0} s \frac{2\pi}{s} \frac{frequency\_deviation\_rate}{s^2} \left(\frac{s^3 \cdot Tb + s^2}{s^3 \cdot Tb + s^2 + s \cdot K \cdot Ta + K} \right) \cdot \frac{1}{2\pi} = \frac{frequency\_deviation\_rate}{K}$$

Phase is integral of frequency

Frequency ramp (triangular modulation)

JTF

Conversion from radians to ratio of the bit rate

- For the clean SSC profiles used in this analysis, a very good match is obtained between the residual jitter predicted by a typical JTF *without peaking* and the residual jitter obtained using the frequency deviation rate calculated over a ~0.3 µs window (0.266us is ideal window size)
- A maximum frequency deviation rate specification is a necessary but non-sufficient condition to guarantee link robustness
  - Averaging the slope over 0.3 µs window does not produce the proper high frequency response

Value of Residual Jitter From SSC Slope (2)

Calculation of the Optimal Window for Slope Measurement

- The approximation of the JTF by a fixed averaging window is a first order approximation of the JTF transfer function.

$$JTF(s) = \frac{\Theta_{out}(s)}{\Theta_{in}(s)} = \frac{s^3 \cdot Tb + s^2}{s^3 \cdot Tb + s^2 + s \cdot K \cdot Ta + K}$$

- The SSC profile is expressed in frequency, which is proportional to the derivative of the phase. Thus, we could re-write the JTF as a ratio between the output phase and the input frequency. Furthermore, we can include the conversion from radians to ratio of the bit rate to get the relative output jitter:

$$JTF'(s) = \frac{Jitter_{out}(s)}{F_{in}(s)} = \frac{1}{2\pi} \cdot \frac{\Theta_{out}(s)}{F_{in}(s)} = \frac{1}{2\pi} \cdot \frac{2\pi}{s} \cdot \frac{\Theta_{out}(s)}{\Theta_{in}(s)} = \frac{\left(s^2 \cdot Tb + s\right)}{s^3 \cdot Tb + s^2 + s \cdot K \cdot Ta + K}$$

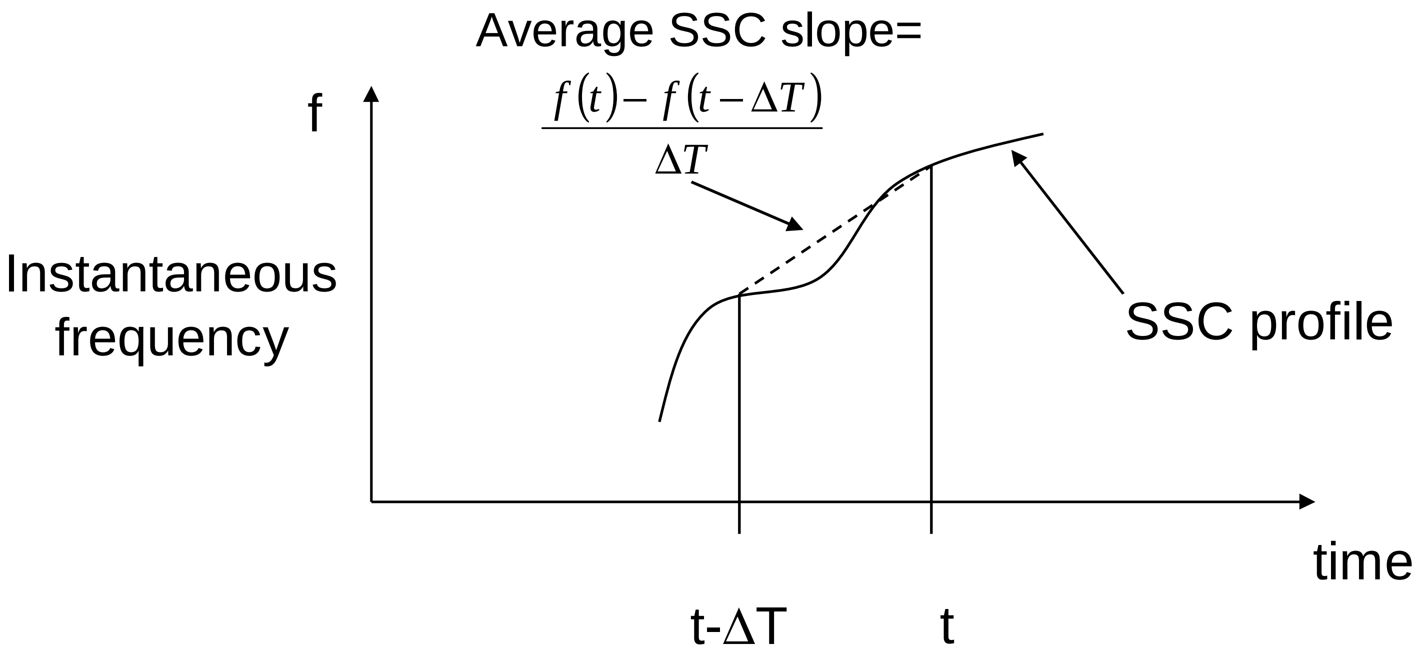
- This function can be expanded in a Taylor series:

$$JTF'(s) \approx \frac{s}{K} + \frac{s^2 (Tb - Ta)}{K} + O\left(s^3\right)$$

Value of Residual Jitter From SSC Slope (3)

Calculation of the Optimal Window for Slope Measurement

- This has to be compared to using the average slope of the SSC profile over some time window. This operation can be seen as the frequency variation between the end and beginning of the window, divided by the window time.



Value of Residual Jitter From SSC Slope (4)

Calculation of the Optimal Window for Slope Measurement

- This average slope process can then be evaluated in the frequency domain:

$$a(t)=\frac{f(t)-f(t-\Delta T)}{\Delta T}\longrightarrow A(s)=\frac{F(s)\cdot(1-e^{-s\cdot\Delta T})}{\Delta T}$$

$$Slope(s)=\frac{A(s)}{F(s)}=\frac{\left(1-e^{-s\cdot\Delta T}\right)}{\Delta T}$$

- To match the JTF, we are allowed to multiply this equation by a fixed constant, C (which should be equal to 1/K, as what the first limit indicated for a constant slope)

$$JTF'_{slope}(s)\approx C\cdot Slope(s)$$

- Again, we use a Taylor expansion

$$JTF'_{slope}(s)\approx C\left(s-s^2\frac{\Delta T}{2}+O\left(s^3\right)\right)$$

Value of Residual Jitter From SSC Slope (5)

Calculation of the Optimal Window for Slope Measurement

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- Finally, we equate the two approximate expressions, ignoring the remaining high-order terms:

$$JTF'_{slope}(s) \approx JTF'(s)$$

$$Cs - Cs^2 \frac{\Delta T}{2} = \frac{s}{K} + \frac{s^2 (Tb - Ta)}{K}$$

- This results in the two solutions:

$$C = \frac{1}{K}$$

As expected from the limit equation:
For a constant slope, we get Jitter=slope/K

$$\Delta T = 2 \cdot (Ta - Tb)$$

Optimal slope window size to match the JTF knee (0.266us for nominal JTF)

- Thus, the best approximation to match the JTF by the slope method is to compute the SSC profile slope over a window of time ΔT=2·(Ta-Tb) and to divide the result by K. This gives a result in a ratio to the bit rate (i.e. ppm-like). It will match up to the second derivative (i.e. terms in s^2).
- Note that ΔT is measured backwards from the current time (when Ta>Tb), to get the best curve fitting.

JTF Residual Jitter vs SSC Profile df/dt (No HF Content)

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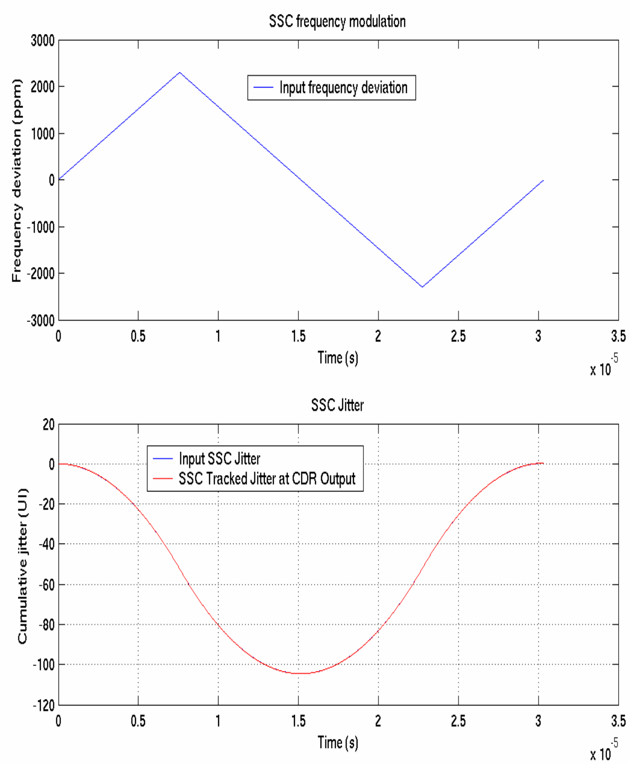
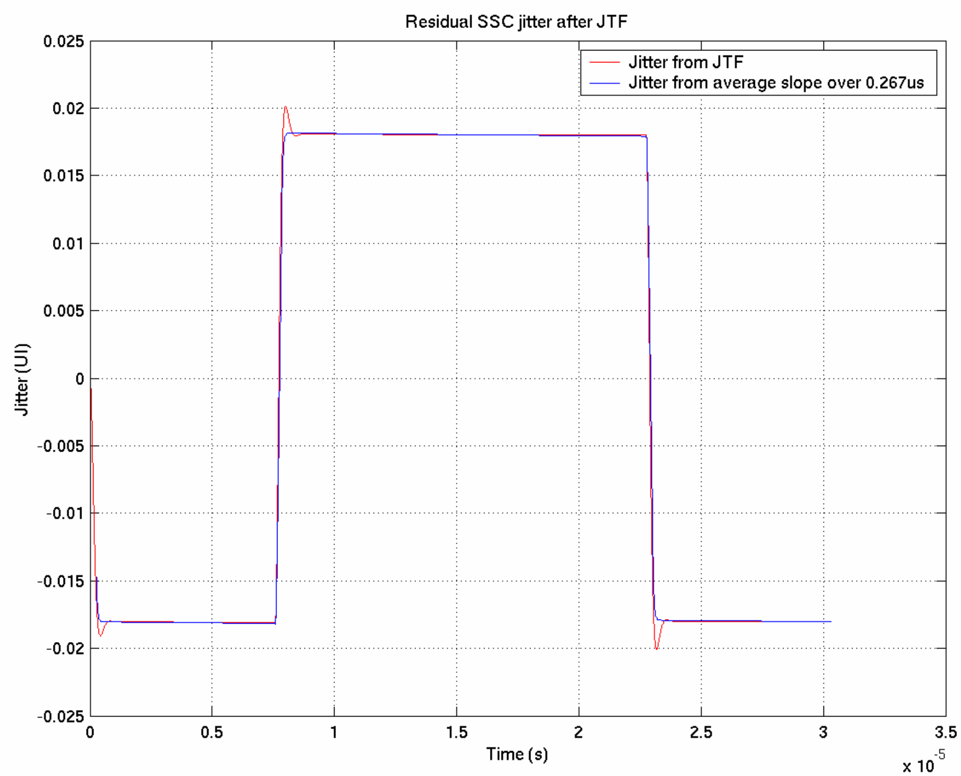
- As presented in 08-027r3, in the absence of high frequency content, there is a very good match between Jitter calculated with the JTF and jitter calculated from the slope of the SSC profile





Frequency Response of the Slope Measurement over a Window (1)

- As shown earlier, the jitter resulting from the average slope process in the frequency domain is:

$$JTF'_{slope}(s) = \frac{jitter_{OUT}(s)}{F(s)} \approx \frac{1}{K} \cdot Slope(s) = \frac{(1-e^{-s\cdot\Delta T})}{K\cdot\Delta T}$$

- To compare this response to the JTF frequency response, we need to express A(s) as a function of the input jitter:

$$F(s) = \frac{s\cdot\Theta(s)}{2\pi} = \frac{s\cdot 2\pi\cdot jitter_{IN}(s)}{2\pi} = s\cdot jitter_{IN}(s)$$

$$jitter_{OUT}(s) = \frac{s\cdot jitter_{IN}(s)\cdot(1-e^{-s\cdot\Delta T})}{K\cdot\Delta T}$$

- To compare this response to the JTF frequency response, we need to express A(s) as a function of the input jitter:

$$JTF'_{SLOPE\_JITTER}(s) = \frac{jitter_{OUT}(s)}{jitter_{IN}(s)} = \frac{s\cdot(1-e^{-s\cdot\Delta T})}{K\cdot\Delta T}$$

Frequency Response of the Slope Measurement over a Window (2)

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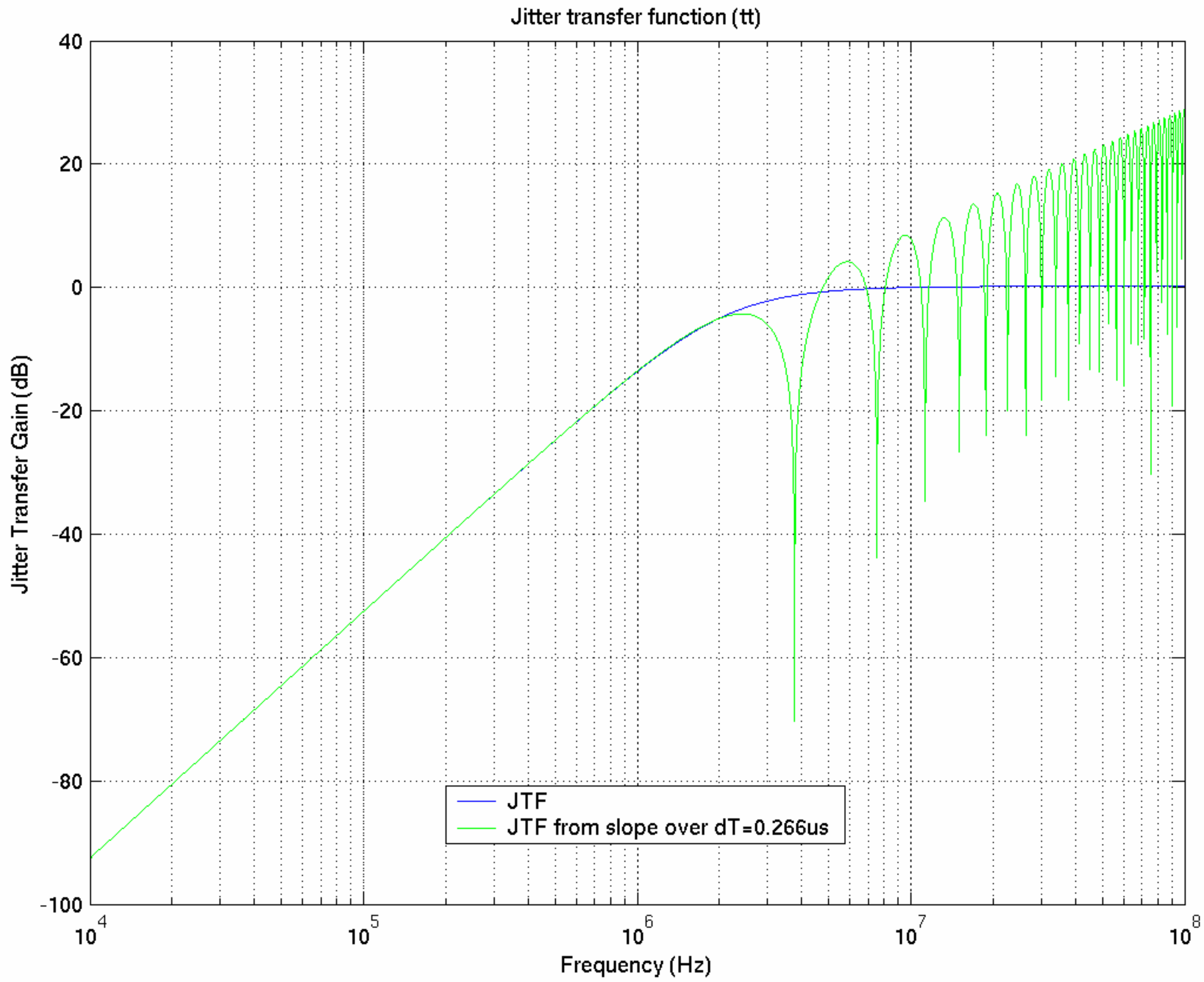
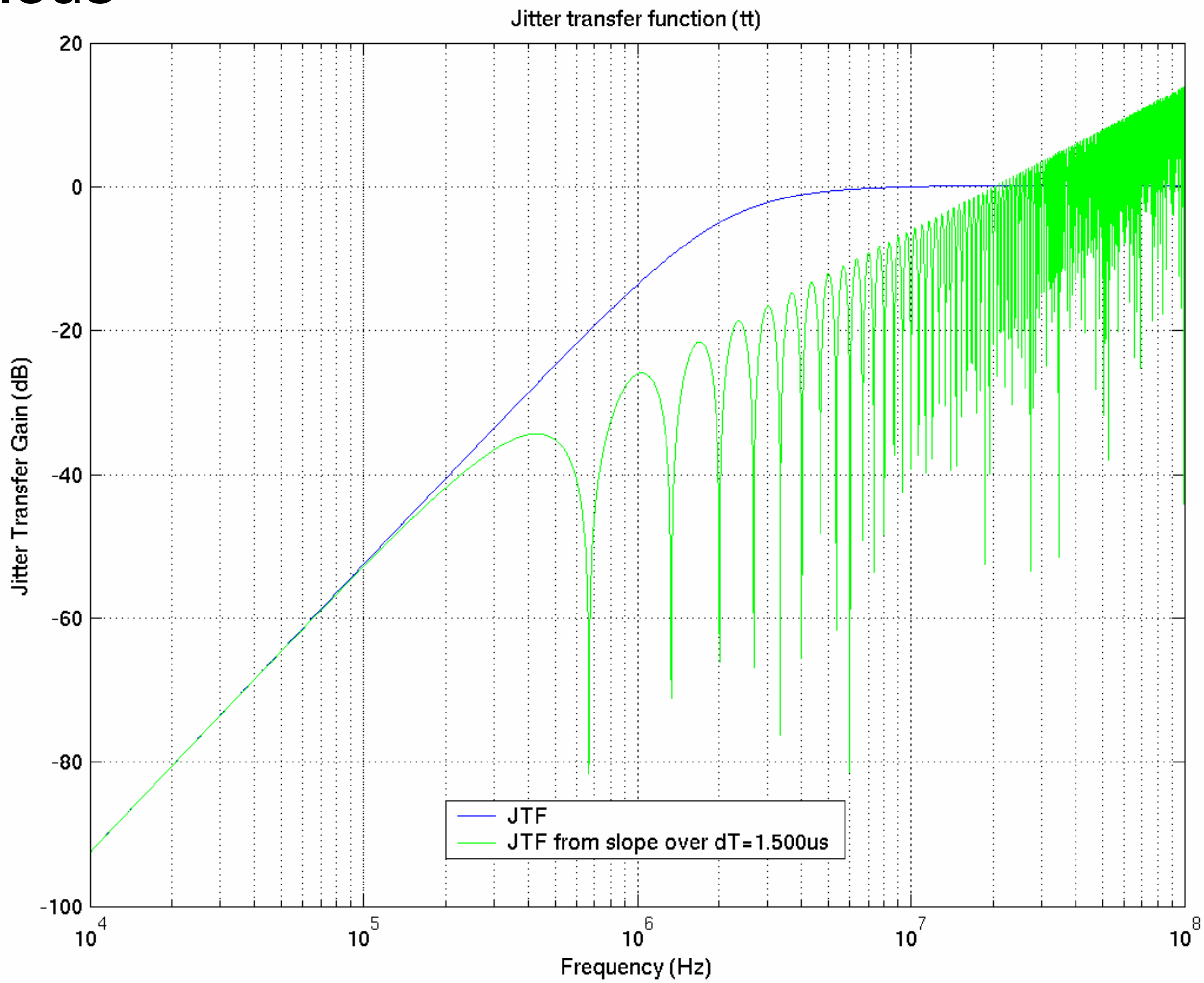
- ΔT=0.266us



Frequency Response of the Slope Measurement over a Window (3)

- ΔT=1.5us



Frequency Response of the Slope Measurement over a Window (4)

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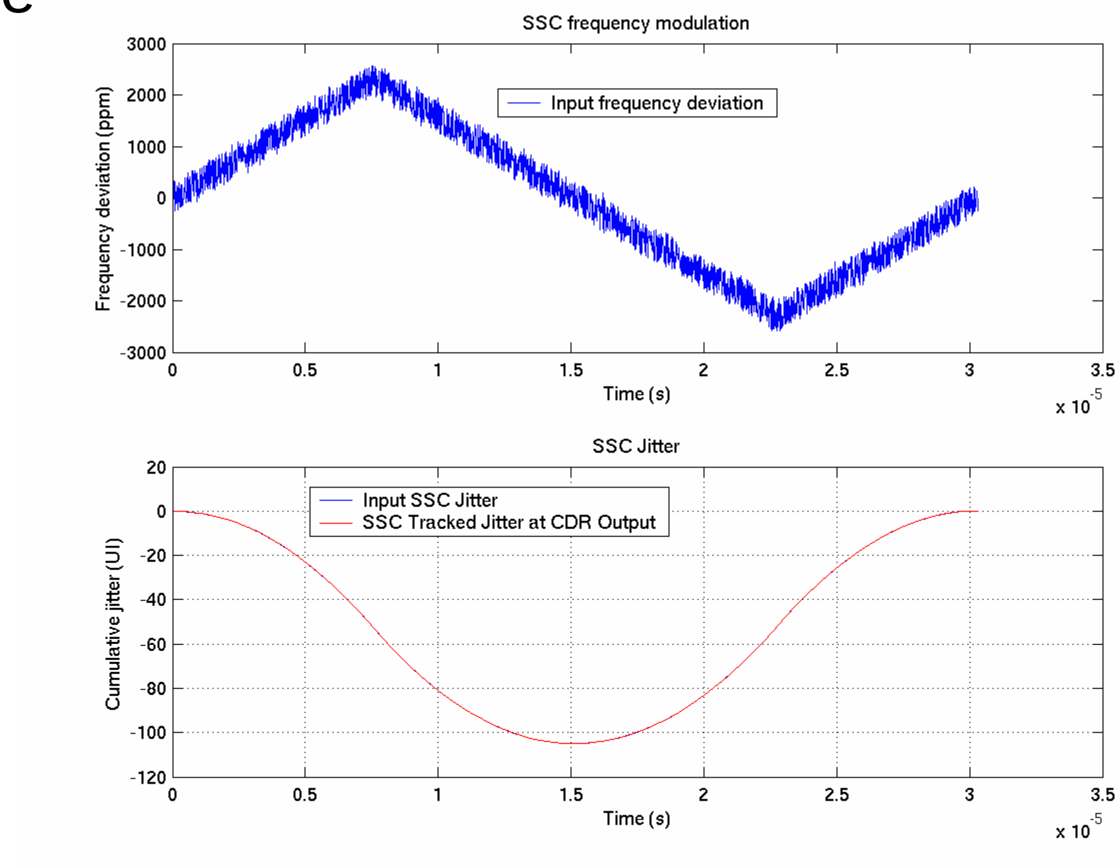
- The slope-based pseudo-JTF response matches well the real JTF up to f=~1/ΔT but:
  - It amplifies high frequency jitter with a gain that increases 20dB per decade
  - There are periodic nulls in the response above f=~1/ΔT

- The slope-based pseudo-JTF is thus unlikely to match the real JTF for real-world SSC profiles with high frequency content.

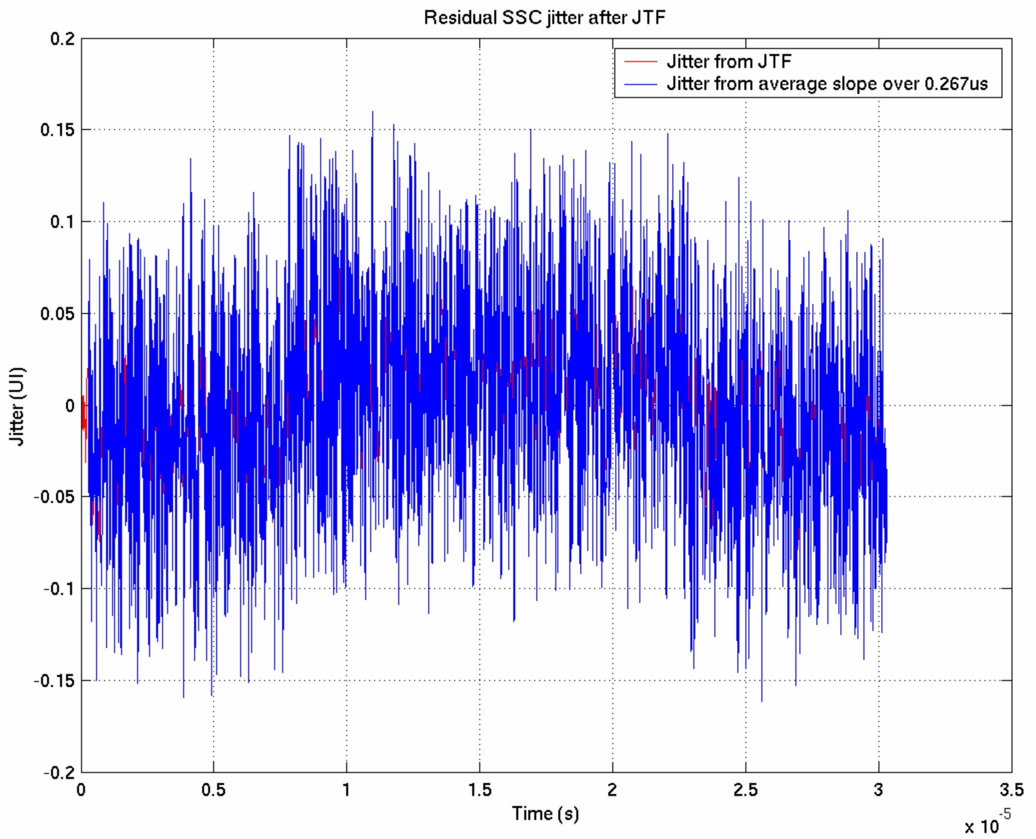
Response of the Slope Measurement To High Frequency Jitter (1)

- +/-300ppm random noise added to triangular SSC profile



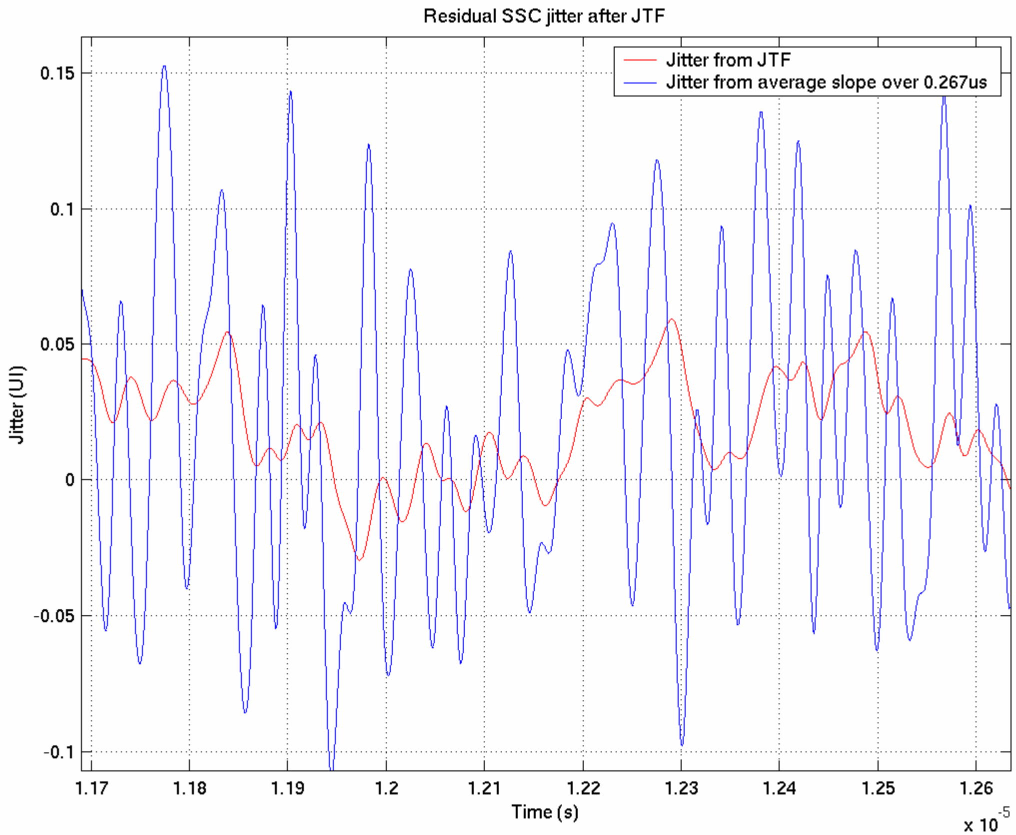
Response of the Slope Measurement To High Frequency Jitter (2)

- Jitter from slope (ΔT=0.267us) is higher than jitter from JTF



Response of the Slope Measurement To High Frequency Jitter (3)

- Jitter from slope (ΔT=0.267us) is higher than jitter from JTF
  - and does not track it at all…



Response of the Slope Measurement To High Frequency Jitter (4)

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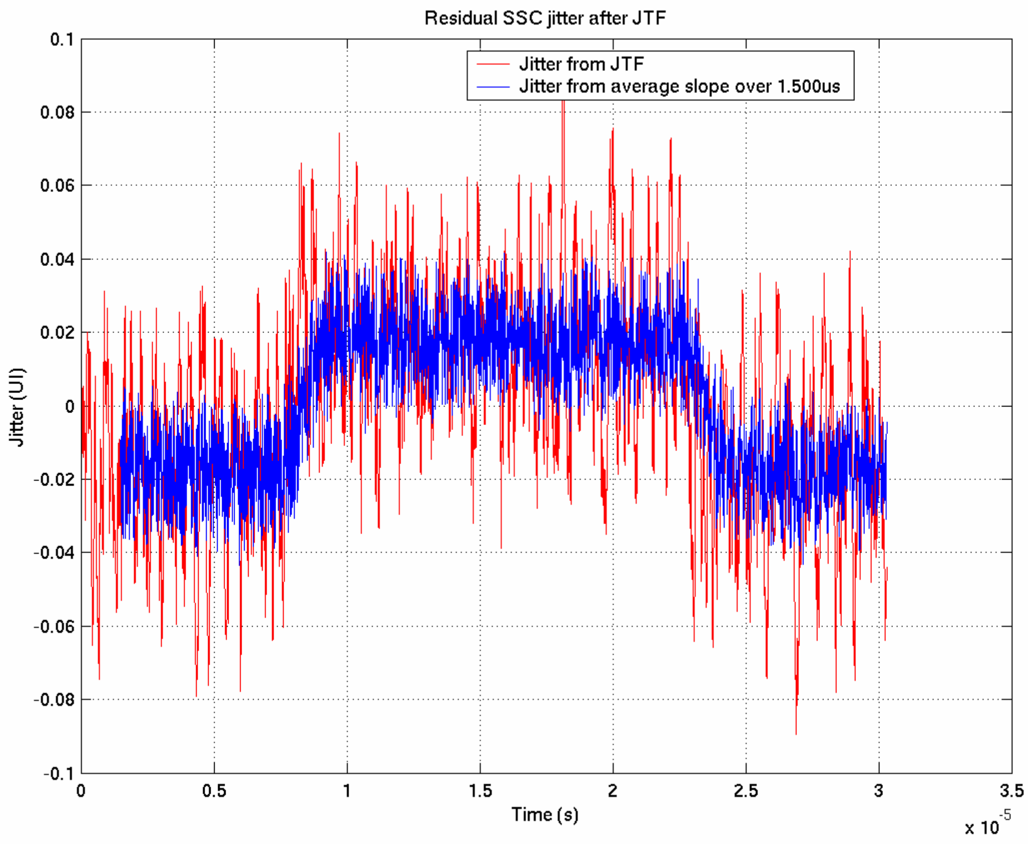
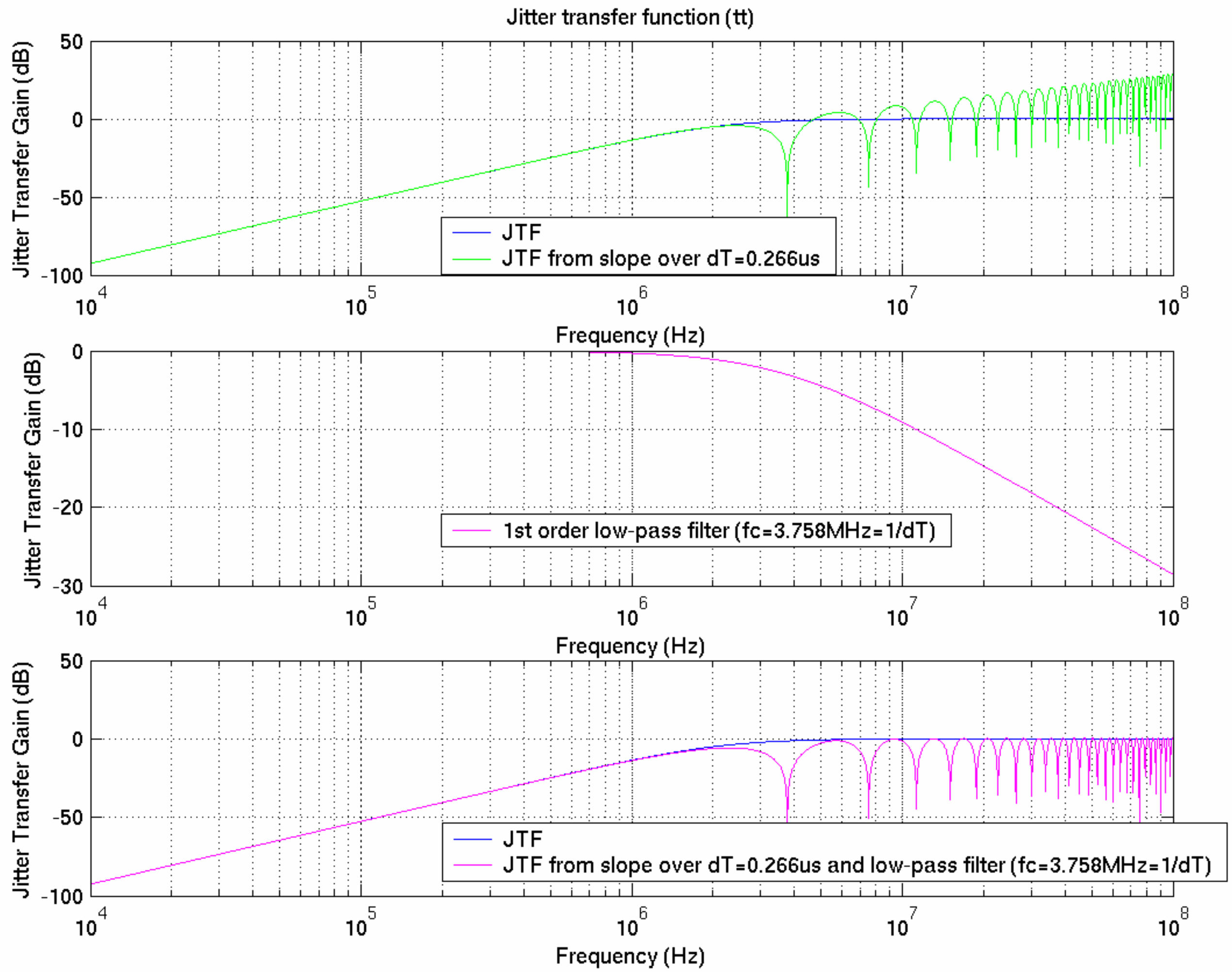
- Jitter from slope (ΔT=1.5us) is lower than jitter from JTF
  - and does not track any better



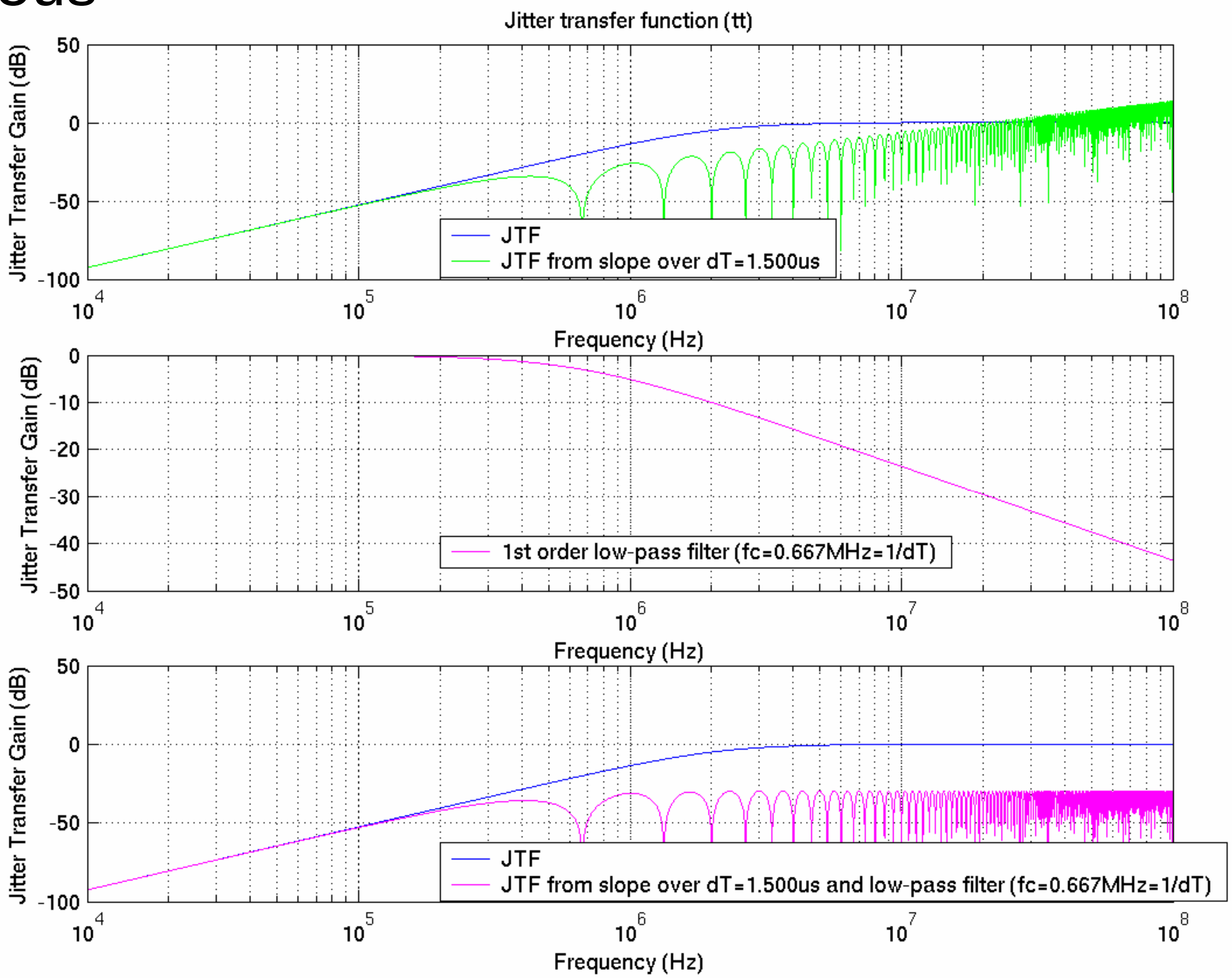
Improving the Slope Measurement With Low-Pass Filtering (1)

- ΔT=0.266us



Improving the Slope Measurement With Low-Pass Filtering (2)

- ΔT=1.5us



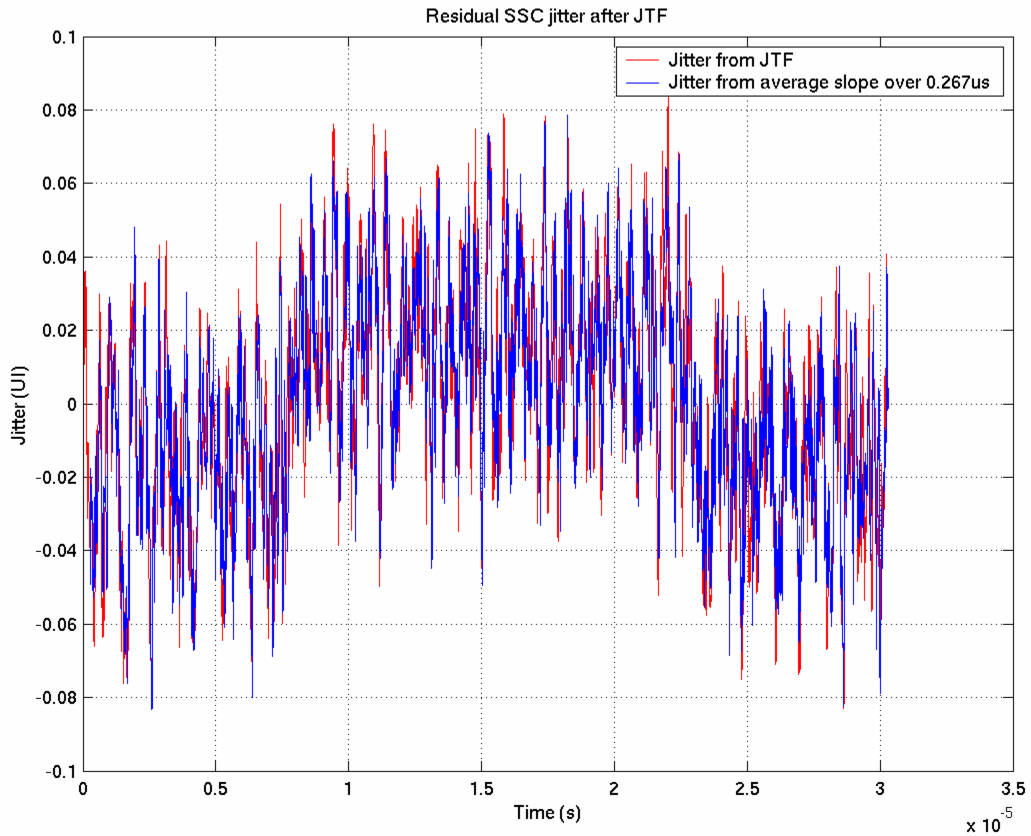
Improving the Slope Measurement With Low-Pass Filtering (3)

- Filtering gets rid of the high frequency jitter amplification
- There are still periodic nulls in the response above f=~1/ΔT

- The slope-based pseudo-JTF is thus unlikely to match the real JTF for real-world SSC profiles with high frequency content.

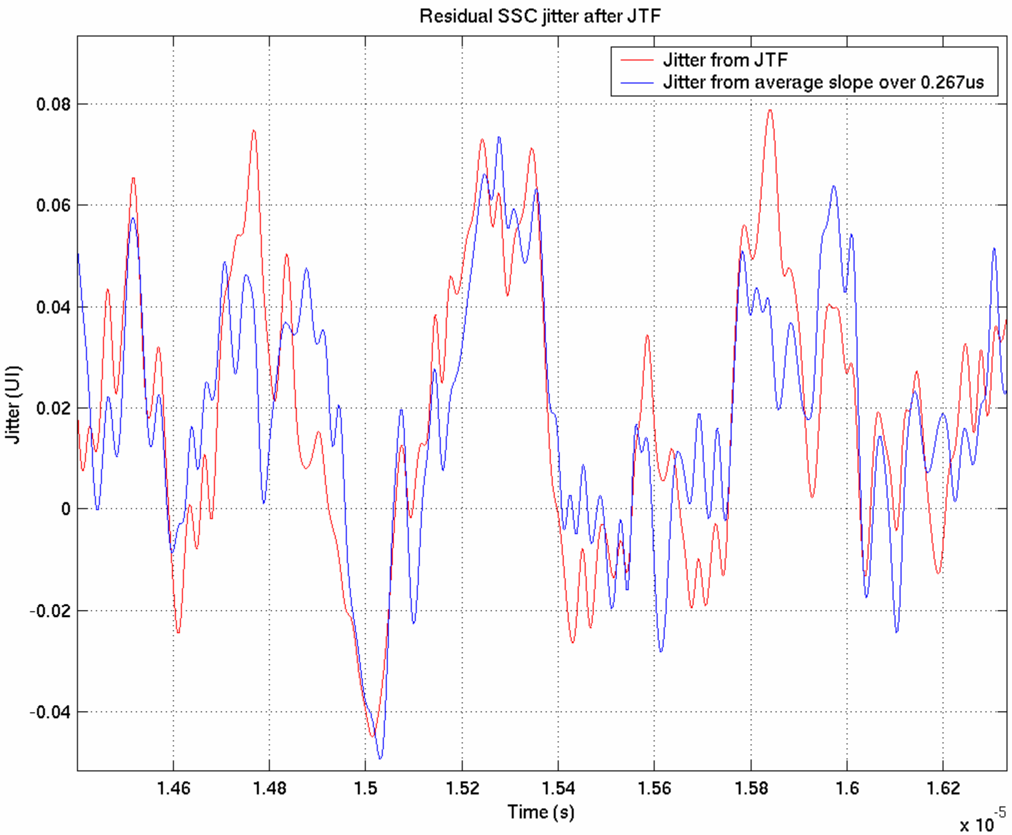
Improving the Slope Measurement With Low-Pass Filtering (4)

- Jitter from slope (ΔT=0.267us) is now lower than jitter from JTF
  - Effect of the HF nulls



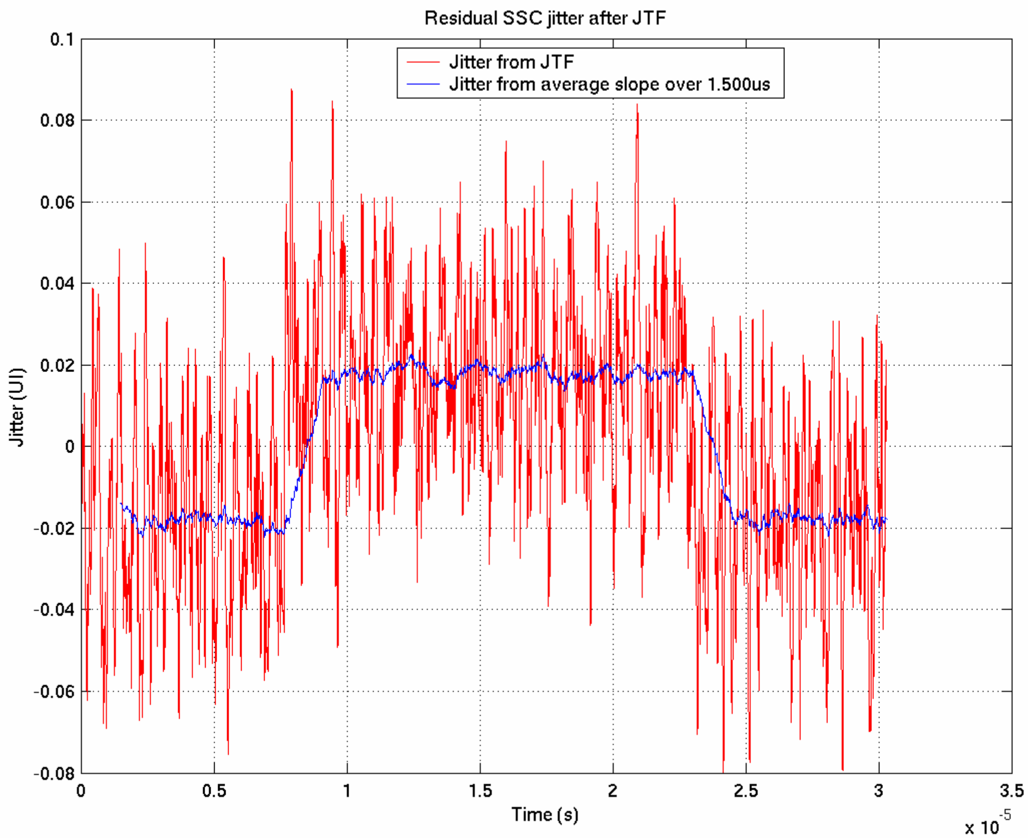
Improving the Slope Measurement With Low-Pass Filtering (5)

- Jitter from slope (ΔT=0.267us) is now smaller than jitter from JTF
  - but still does not track very well…



Improving the Slope Measurement With Low-Pass Filtering (6)

- Jitter from slope (ΔT=1.5us) is much lower than jitter from JTF



Conclusions

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- The slope-based pseudo-JTF response matches well the real JTF up to f=~1/ΔT
  - With 1.5us window, it can cover ~20 harmonics of the SSC modulation
  - With 0.27us window, it can cover ~100 harmonics of the SSC modulation
- High-frequency jitter causes the slope-based pseudo-JTF to diverge from the real JTF
  - In the presence of high frequency noise, the slope measurement of an SSC profile is not a good predictor of that profile's compliance to the jitter specifications.

It is proposed to keep the JTF as the only filtering method for transmitter jitter measurements, with or without SSC