QAM-Based 1000BASE-T Transceiver

Oscar Agazzi, Mehdi Hatamian, Henry Samueli

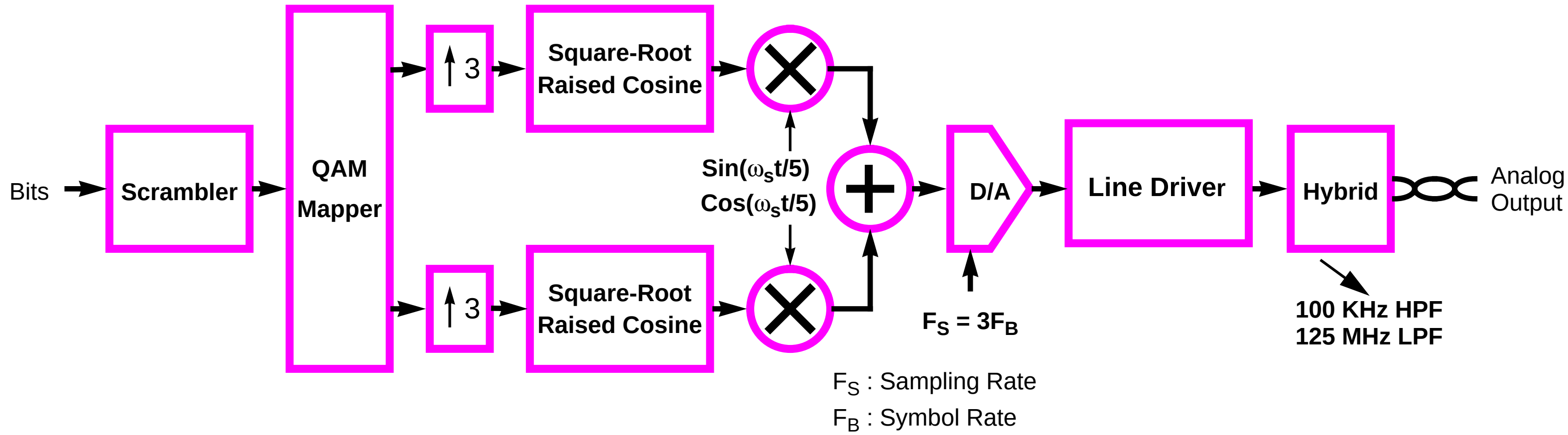
Broadcom Corp.

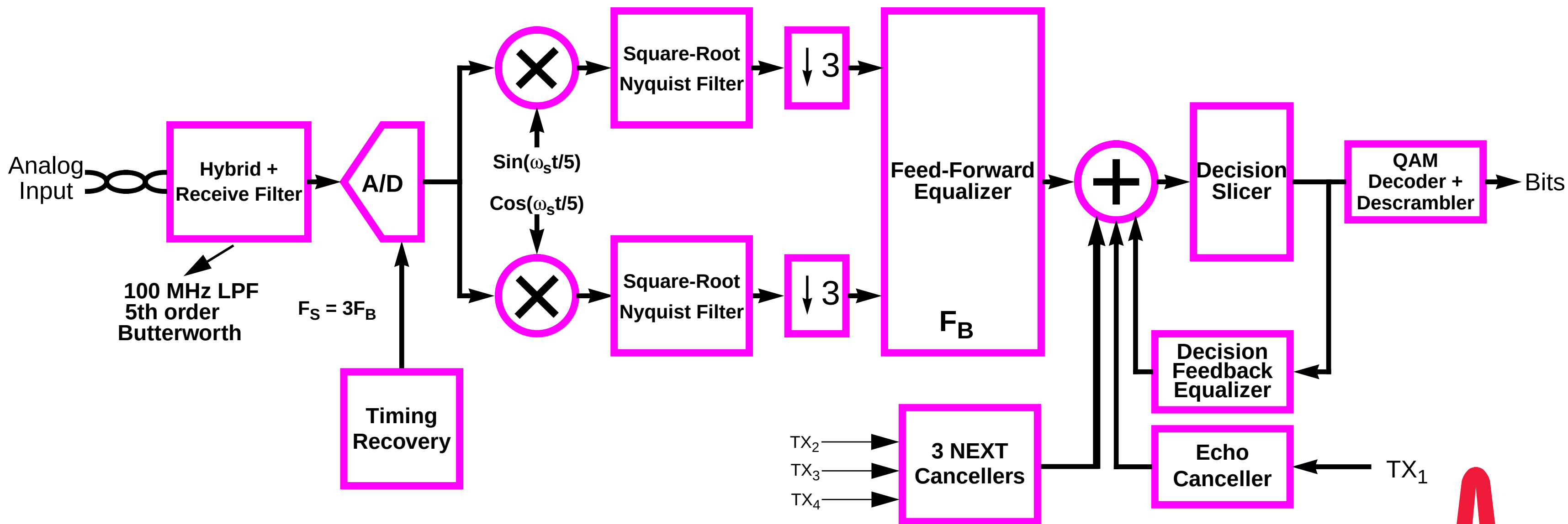
16251 Laguna Canyon Rd.
Irvine, CA 92618
714-450-8700

Overview

- The FEXT problem
- FEXT results
- Jitter model
- Update simulation results
- Conclusions

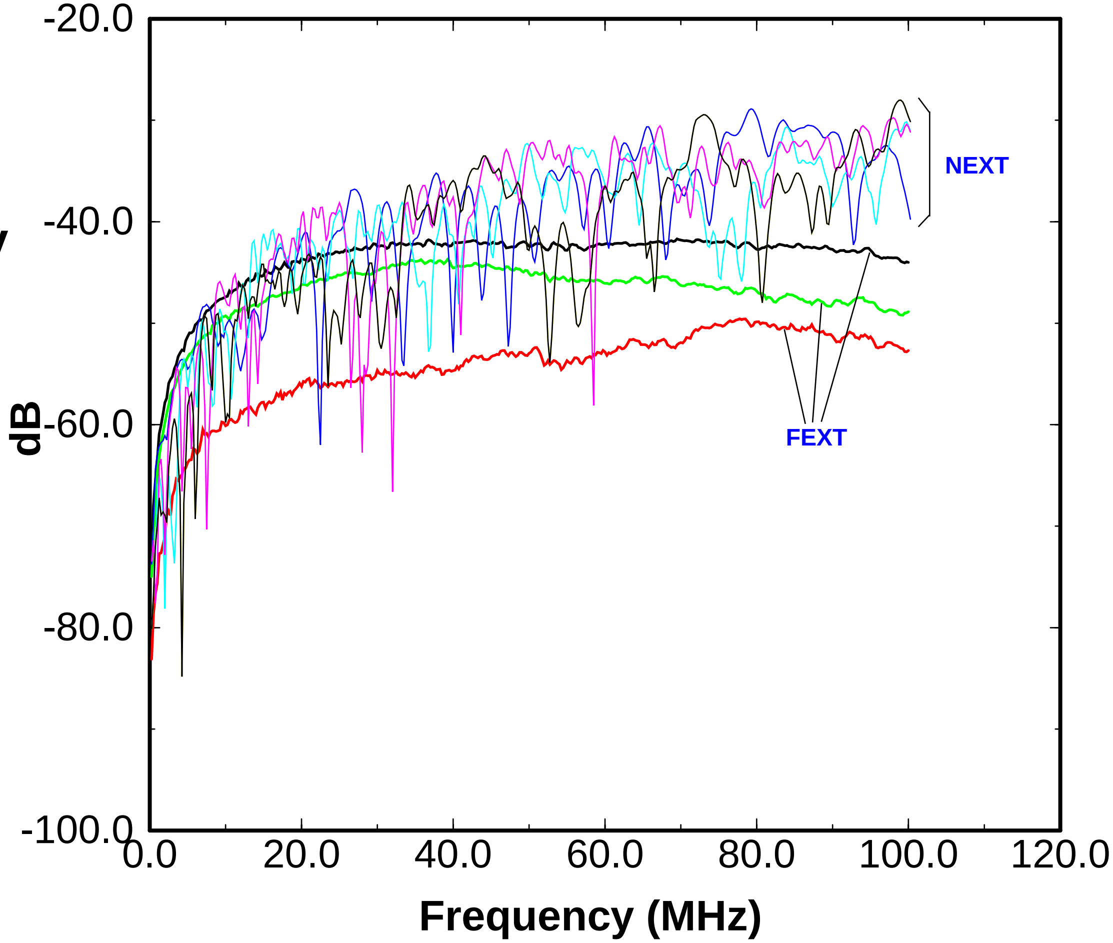
QAM Transceiver





The FEXT Problem

- **3 measured FEXT curves from Lucent**
- **The FEXT is not negligible by any means**



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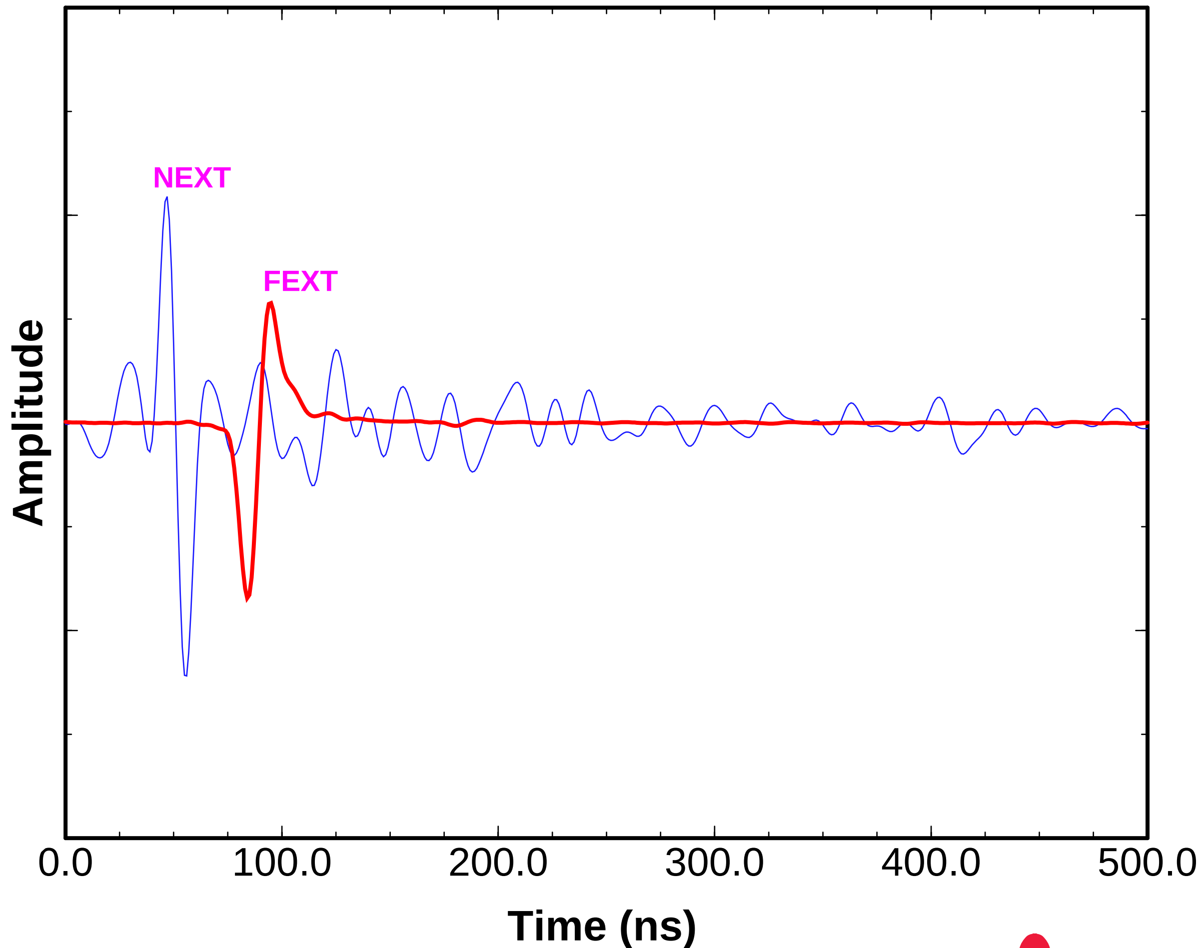
FEXT Impulse Response

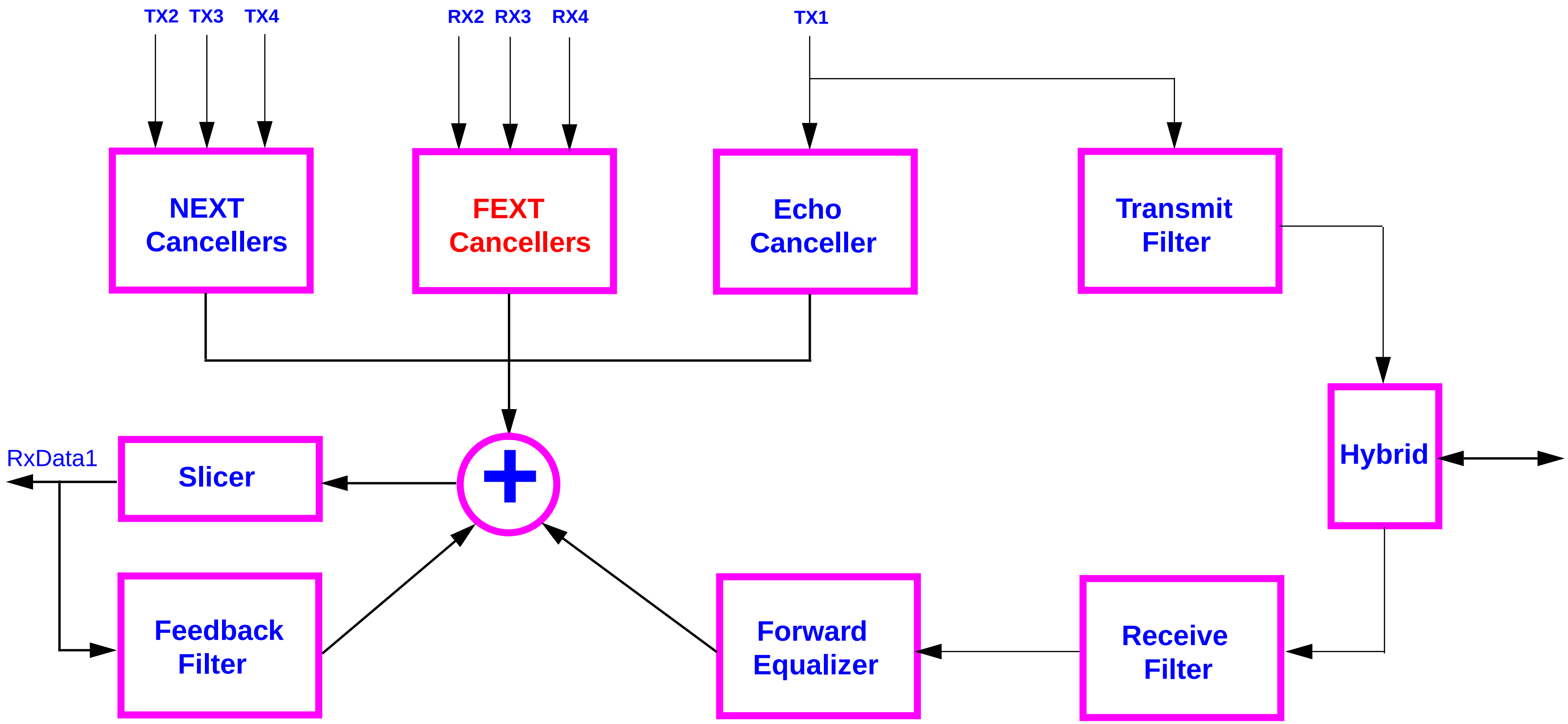
- **Comparable to NEXT in amplitude**



FEXT Cancellation

- FEXT is a potential problem.
- Interference cancellation is normally impractical due to lack of access to the data meant for other receivers.
- In a 1000Base-T transceiver, interference cancellation is a possibility because the data sequences for the interfering pairs have to be decoded anyway.

FEXT Canceller

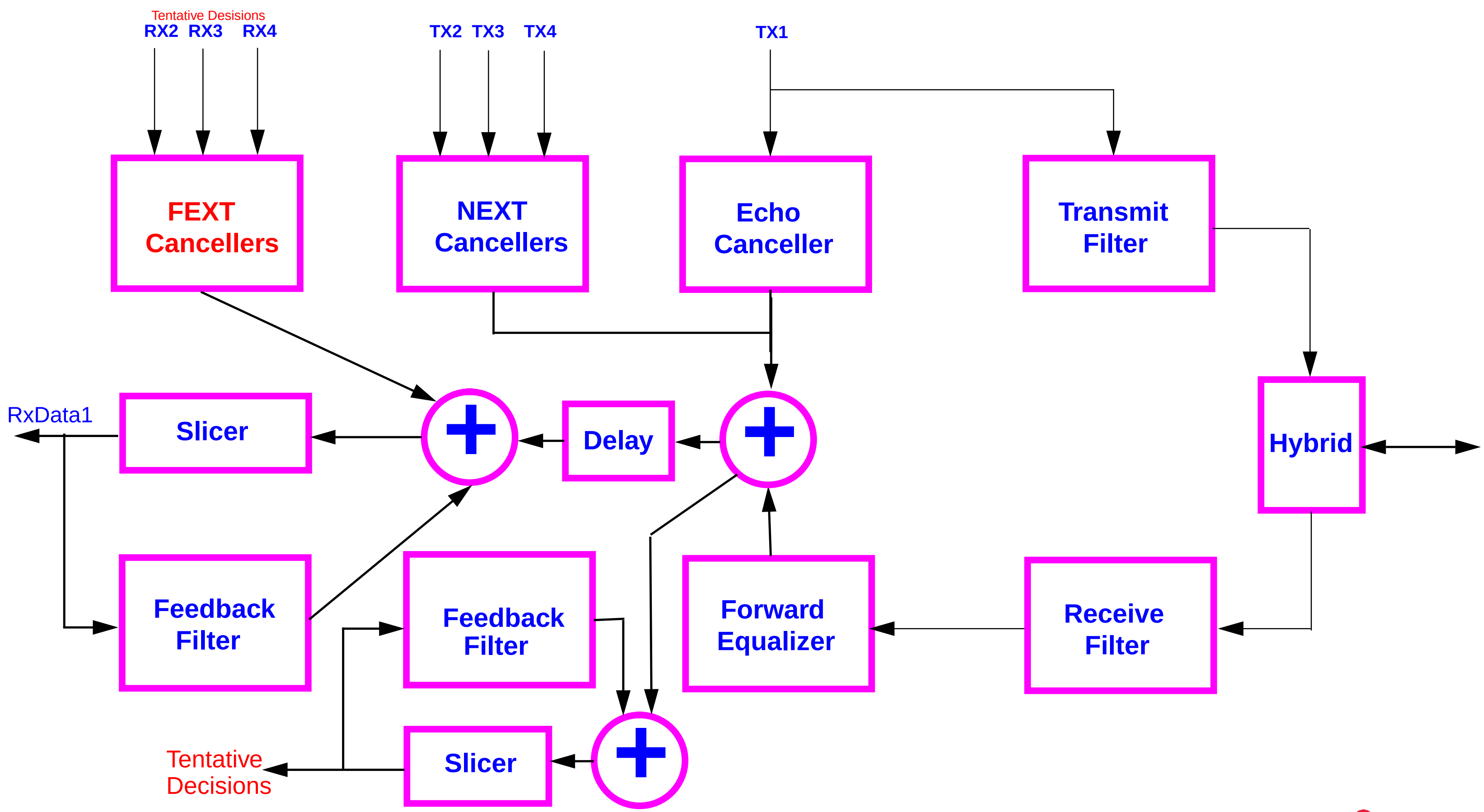


The FEXT Delay Problem

- **The group delay of the FEXT impulse response relative to the cable loss response has not been characterized.**
- **If the relative group delay is negative, FEXT cancellation is still possible using a scheme based on tentative decisions*.**

* *Oscar E. Agazzi and Nambi Seshadari*, "**On the Use of Tentative Decisions to Cancel Intersymbol Interference and Nonlinear Distorsion**," IEEE Transactions on Information Theory, Vol. 43, No. 2, March 1997, pp.1-15

FEXT Canceller



The two feedback filters can be shared in implementation.

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Effect of FEXT on Margin

Configuration	QAM-25		PAM-5	
Without FEXT	9.95dB	3.05dB	9.73dB	3.17dB
With FEXT	6.95dB	1.55dB	6.22dB	1.3dB
With FEXT & FEXT Cancellers	9.93dB	3dB	9.7dB	3.1dB

- **PAM-5 simulations assume the use of Viterbi decoder and that it can be effective in conjunction with the DFE.**
- **QAM-25 results assume the use of 8D coding.**
- **FEXT cancellers can effectively restore the lost margin.**

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The Jitter Issue

- Need a realistic model for jitter.
- A realistic characterization of jitter should take into account not only the peak-to-peak or rms value of the jitter but also its power spectral density.
- We propose a realistic jitter model to be used in simulations. This model is derived based on existing literature, measurements, and extensive discussions with experts in the field.

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Sources of Jitter

- Jitter does not come from Mars!
- The local oscillator
- The remote oscillator
- The timing recovery process

Jitter Behavior

- The jitter by the local oscillator will be attenuated by the PLL provided that the loop bandwidth is larger than the bandwidth of the jitter.
- Jitter in the received signal due to remote oscillator and remote timing recovery will be tracked if the bandwidth of the PLL is larger than the bandwidth of the jitter.
- Jitter due to local timing recovery can be reduced using a narrow band loop.
- Even relatively large values of rms jitter can have little effect on the receiver performance if the condition $B_{PLL} > B_{jitter}$ can be satisfied.
- The choice of PLL bandwidth is a tradeoff between data dependent jitter in recovered clock and intrinsic jitter filtering/tracking performance.

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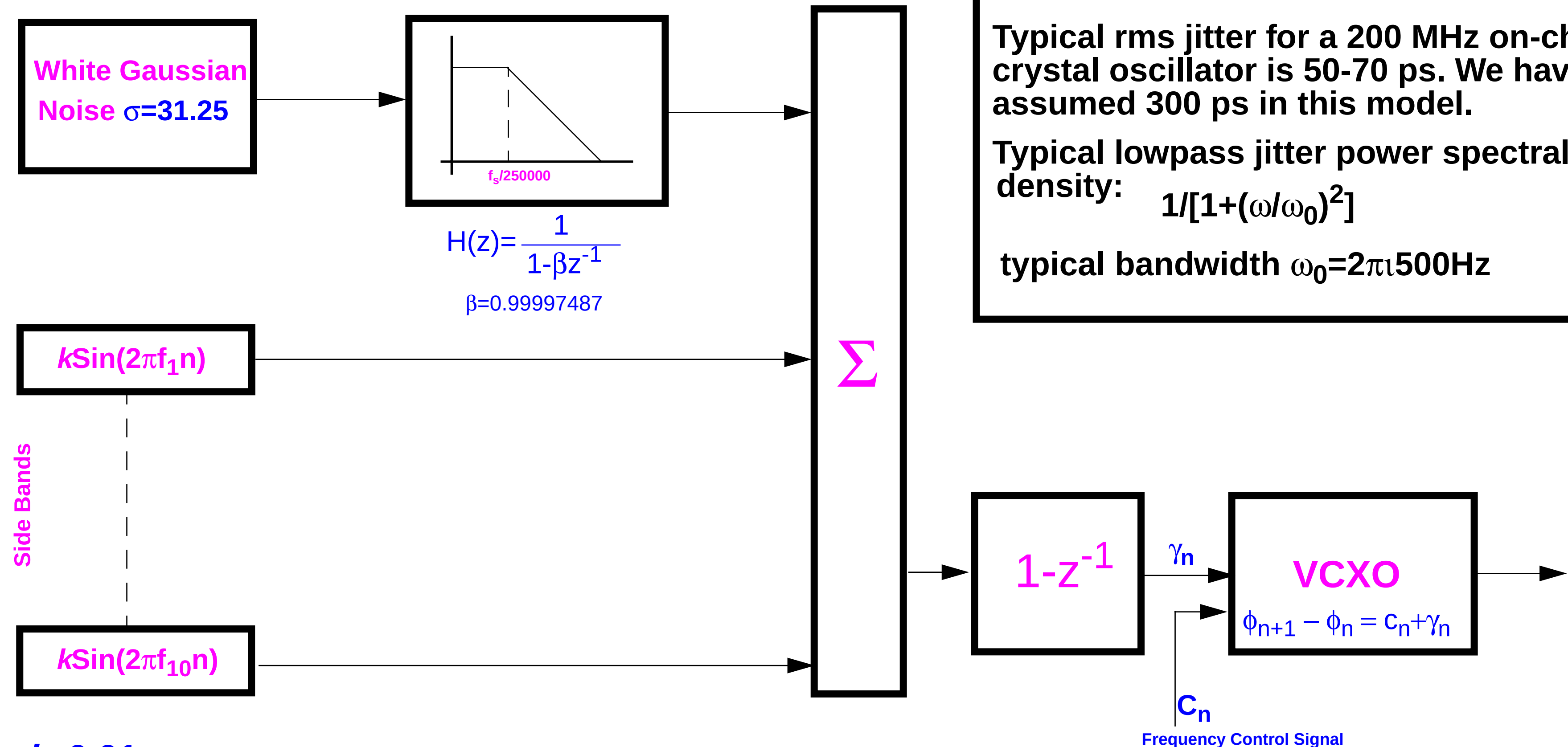
Proposed Jitter Model for VCXO

Typical rms jitter for a 200 MHz on-chip crystal oscillator is 50-70 ps. We have assumed 300 ps in this model.

Typical lowpass jitter power spectral density: $1/[1+(\omega/\omega_0)^2]$

typical bandwidth $\omega_0=2\pi\cdot 500$**Hz**



k=0.01

40dB down from carrier

f_1/f_s=8.133331e-5 f_2/f_s=1.704673e-4 f_3/f_s=2.278352e-4 f_4/f_s=3.371772e-4 f_5/f_s=4.222677e-4

f_6/f_s=5.111033e-4 f_7/f_s=6.213375e-4 f_8/f_s=7.411157e-4 f_9/f_s=9.227653e-4 f_{10}/f_s=1.087743e-4

From Low Pass Noise to Jitter Spectrum

Phase modulation for small phase is approximately amplitude modulation.
Low pass noise spectrum must be phase (not frequency) modulated to appear as sidebands of the oscillator's nominal frequency

$$x(t)=ACos[\omega_s t+\Phi_m(t)]$$

If $\Phi_m(t)=\Phi_m Sin\omega_m t$ and $\Phi_m<<1$ radian, then:

$$x_1(t) = ACos\omega_s tCos(\Phi_m Sin\omega_m t) - ASin\omega_s tSin(\Phi_m Sin\omega_m t)$$
$$\approx ACos\omega_s t - (ASin\omega_s t)(\Phi_m Sin\omega_m t)$$
$$= ACos\omega_s t + A\Phi_m/2\ [Cos(\omega_s+\omega_m)t - Cos(\omega_s-\omega_m)t]$$

So, the sinusoidal jitter appears as sidebands at $\omega_s \pm \omega_m$

If $\Phi_m(t)$ is a stationary Gaussian random noise with lowpass power spectral density:

$$P_\phi(\omega)= 1/[1+(\omega/\omega_s)^2]$$

and $|\Phi_m| << 1$, then:

$$x_2(t) \approx ACos\omega_s t + A\Phi_m(t)Sin\omega_s t$$

and the resulting spectrum exhibits noise skirts around the center frequency.

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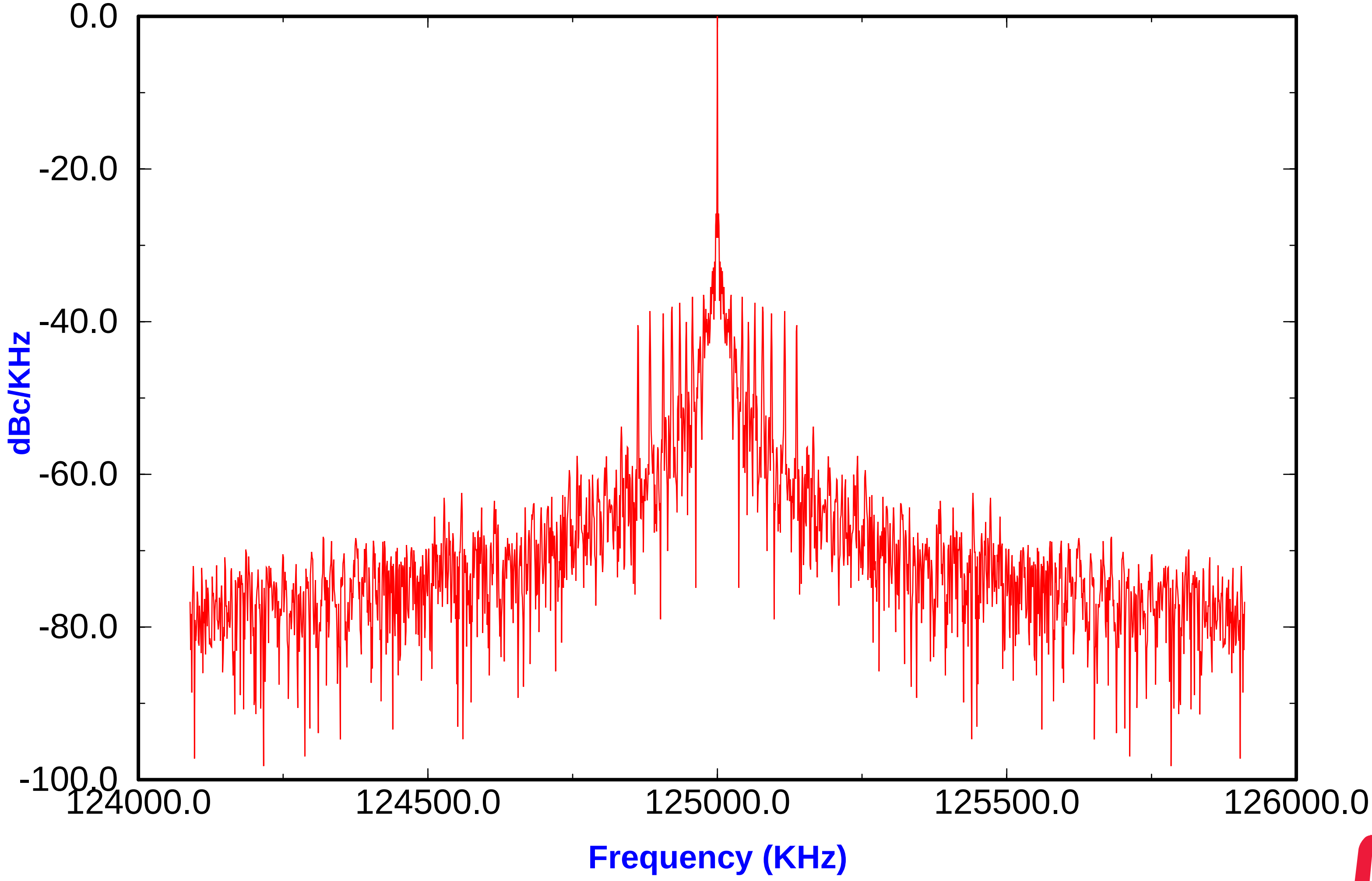
Jitter Model Plot



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Effect of Jitter on Margin

- **With a 0.3ns rms jitter for a crystal oscillator, using the proposed model and closing the timing recovery loop in our simulations, approximately 0.6 dB of degradation in the margin is observed for both QAM and PAM systems.**

- **The effect of jitter should always be evaluated with a closed timing recovery loop in the simulations.**

- **More work to be done on this subject.**

3dB and 10dB Design Points

Parameters	QAM-25, 3dB	QAM-25, 10dB
A/D resolution	6 @187.5MHz	7 @ 187.5MHz
D/A resolution	6 @187.5MHz	7 @187.5 MHz
Baud Rate	62.5 MHz	62.5 MHz
Real FFE Taps	16 @ 125MHz	20 @125MHz
Real DFE Taps	20 @ 125MHz	20 @125 MHz
Real NEXT Taps	18 @ 125MHz	50 @ 125MHz
Real Echo Taps	50 @125MHz	120 @ 125MHz
BLW Cancellation	NO	NO
Viterbi Decoder	NO	NO
Latency	37BT	37BT
Actual Margin	3.05dB	9.95dB
Margin with FEXT	1.55dB	6.95dB
Margin with FEXT Cancellation	3dB	9.93dB
Estimated Gate Count	230K	500K
Estimated Power including analog	3.8W, 0.35µm CMOS 2.7W, 0.25µmCMOS	5.8W, 0.35µm CMOS 4W, 0.25mm CMOS

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Open Issues

- Details of 8D coding for the QAM-25.
- Proof that Viterbi decoding can provide the extra margin in conjunction with DFE.
- More jitter and timing recovery evaluations.
- Possible bit error rate simulations.

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Conclusions

- FEXT cannot be neglected
- Use of FEXT cancellation may be necessary
- Jitter performance should be evaluated by closing the timing recovery loop in the simulations and using a realistic jitter model.
- Bit error rate simulations?

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