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# 10GBASE-KR Transmit Equalizer Requirements


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# Scope and Purpose

- Investigate the impact of imperfect transmit equalization settings on link performance.
- Establish bounds on the range and accuracy of transmit equalizer settings.

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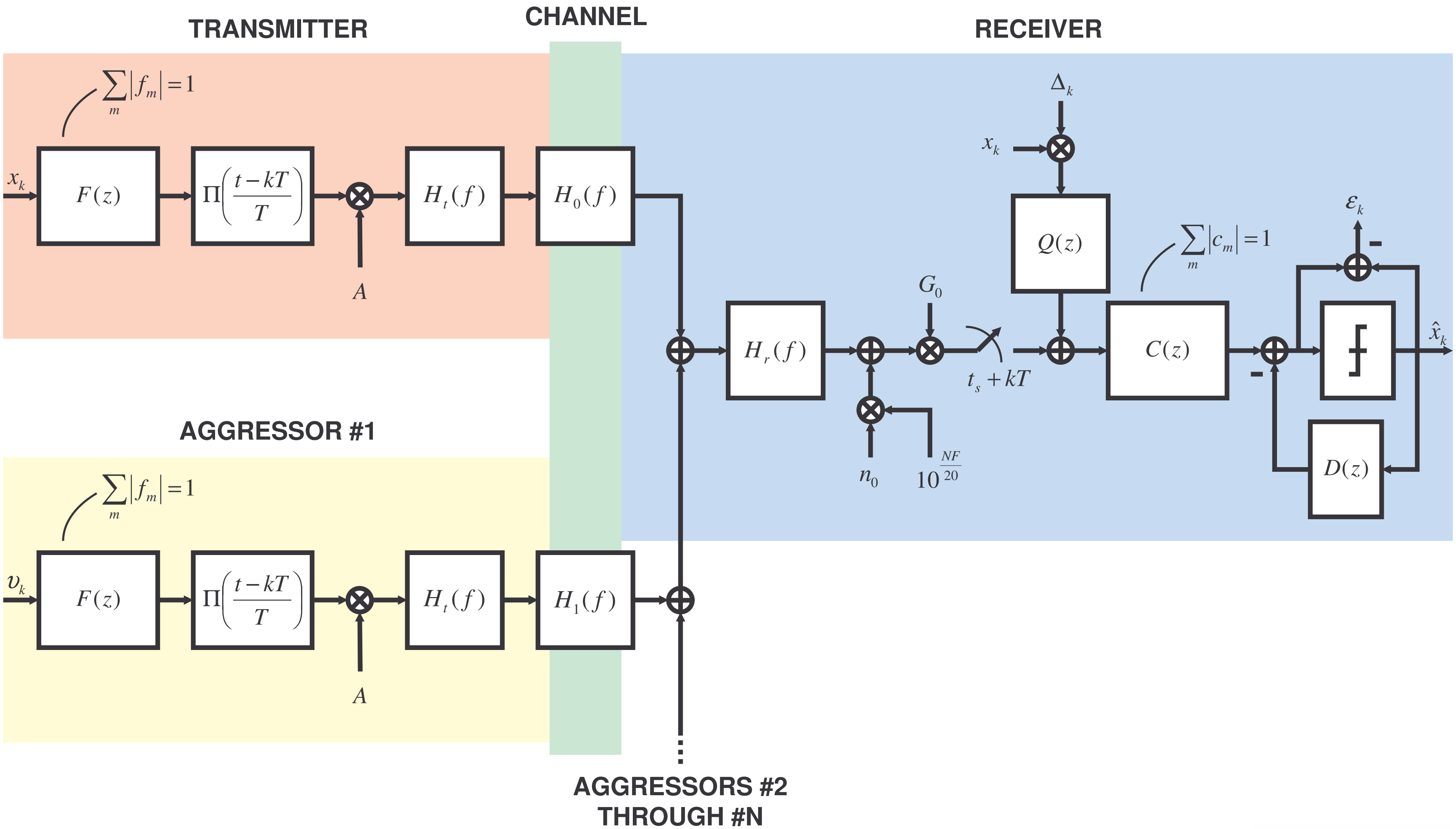
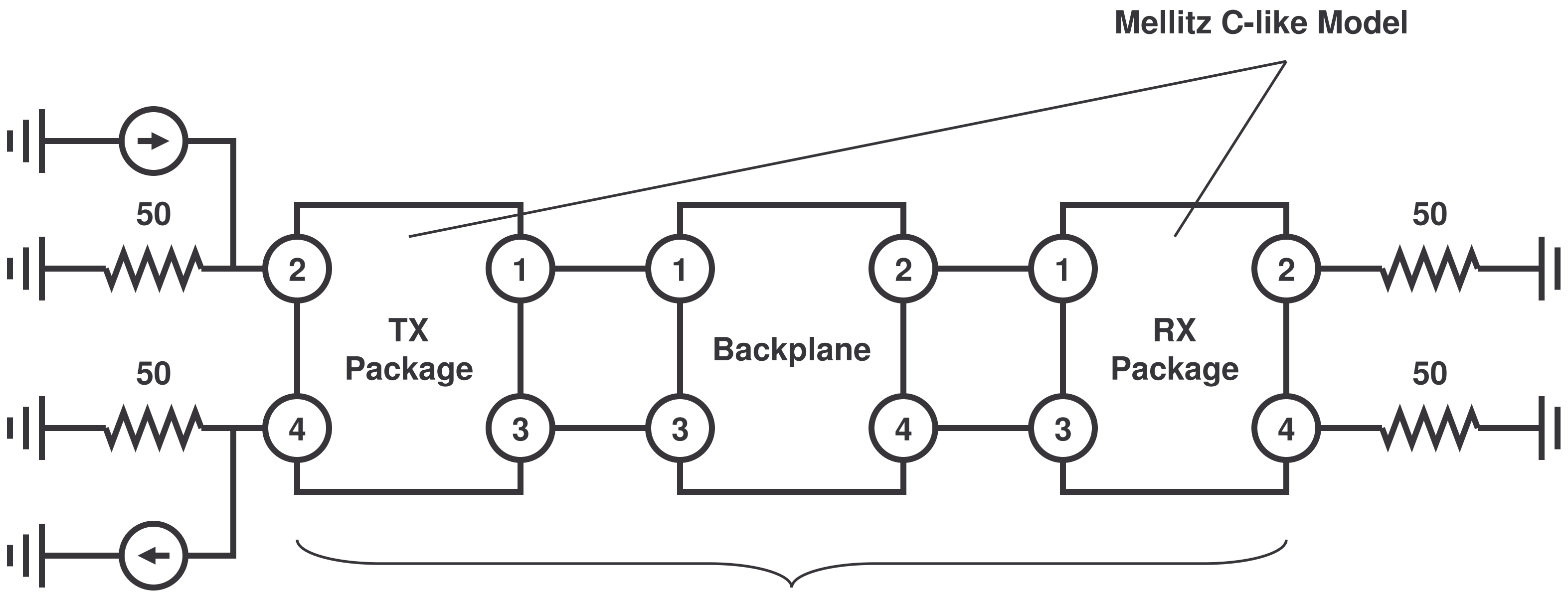
# Simulator Overview

# Analytic Model



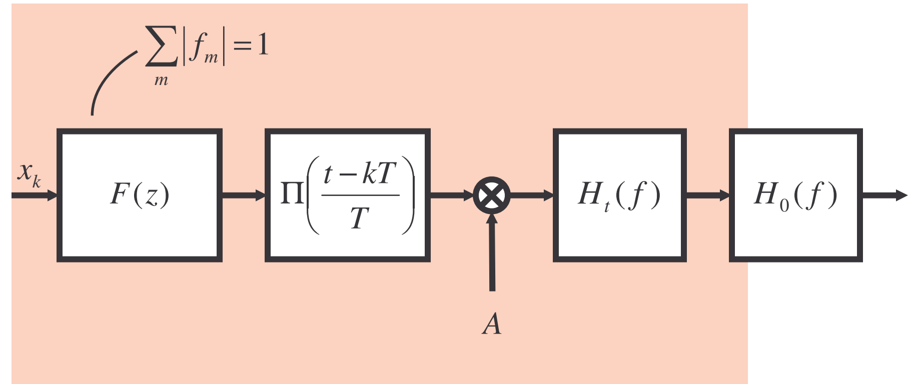
# Channel Model




**$H_0$( f ) – THRU**
**$H_1$( f ) through $H_N$( f ) – NEXT and FEXT**

# Transmitter Model

- 1/T = 10.3125 GHz
- F(z) is the 3-tap transmit FIR
  - Settings for transmitter and aggressors are identical
- A = 400 mV
- $H_t(f)$ yields a trapezoidal pulse with 24 ps rise time (20-80%)




$$f_0 = 1 - |f_{-1}| - |f_1|$$



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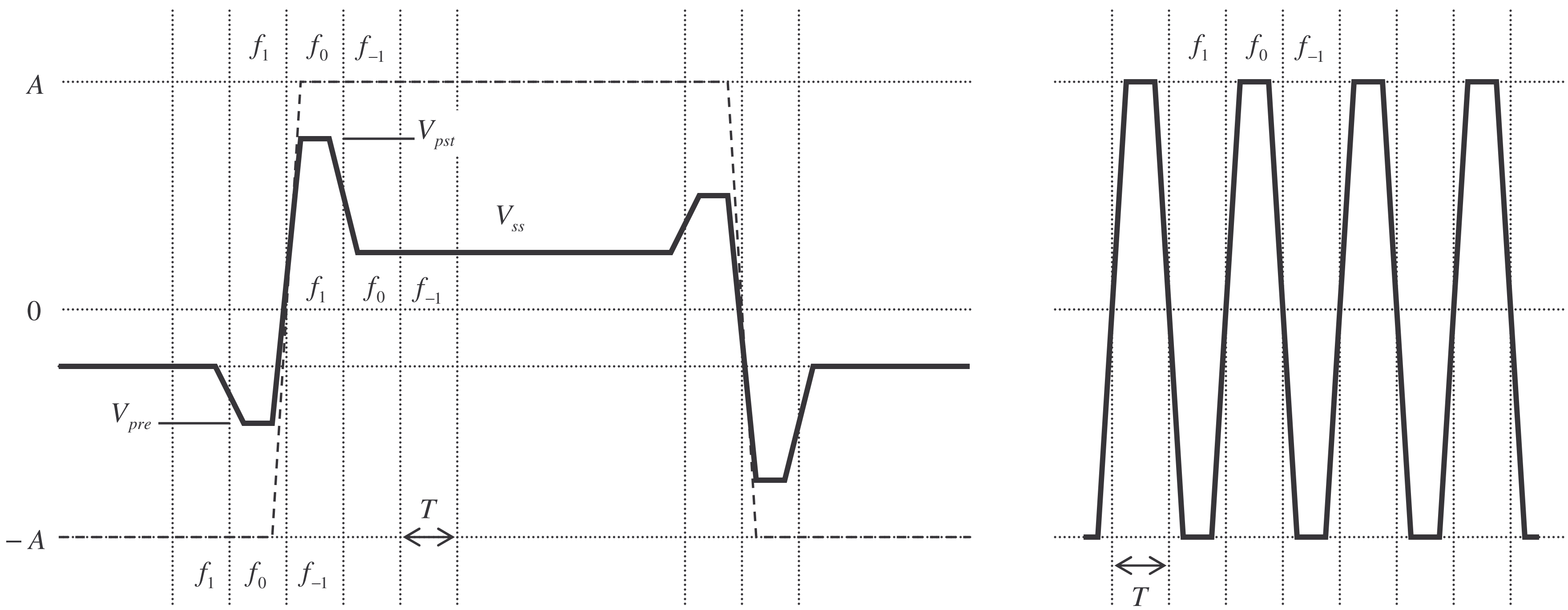
# F(z) Signal Shaping




$$V_{pre} = A(-f_1 - f_0 + f_{-1})$$

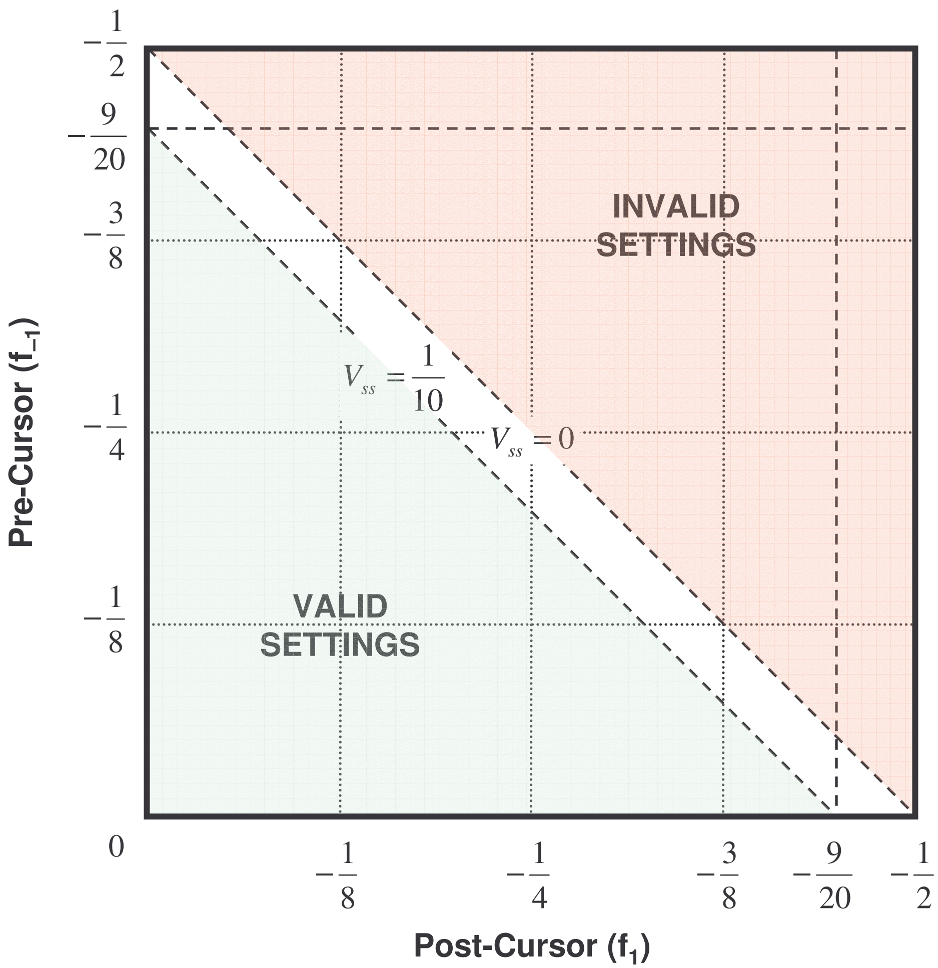
$$V_{pst} = A(-f_1 + f_0 + f_{-1})$$

$$V_{ss} = A(f_1 + f_0 + f_{-1})$$

$$-f_1 + f_0 - f_{-1} = 1$$

**NOTE:**
**By convention, $f_1$ and $f_{-1}$ are always negative and $f_0$ is always positive.**

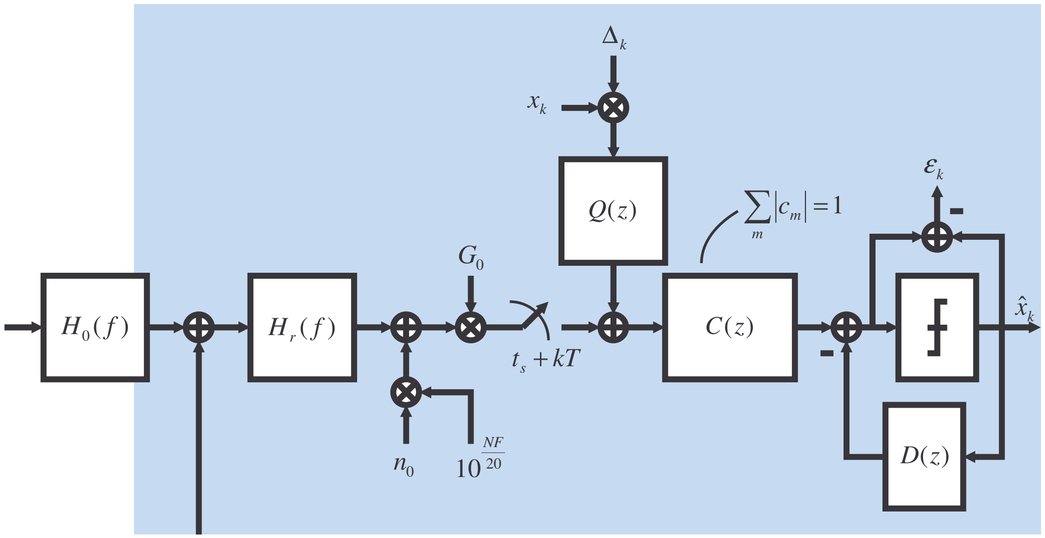
# F(z) Search Space




- **$f_{-1}$ : 37 steps from 0 to −9/20**
- **$f_1$ : 37 steps from 0 to −9/20**
- **$V_{ss}$ : minimum value must be no less than 1/10**

# Receiver Model

- $H_r(f)$ is a 2-pole filter
  - $p_1 = 0.7/T$, $p_2 = 1.0/T$
- $n_0 = 133\ \mu V_{rms}$
- NF = 24 dB
- $G_0 = 1$
- $\Delta_k$ is timing jitter
  - $PJ_t = 0.15\ UI_{p\text{-}p}$
  - $RJ_t = 0.15\ UI_{p\text{-}p}$ at 1E-12
  - $RJ_r = 0.15\ UI_{p\text{-}p}$ at 1E-12
- $C(z)$ is a feed-forward equalizer
  - not used
- $D(z)$ is a 5-tap DFE
- $t_s$, $C(z)$, and $D(z)$ are chosen to minimize $E[\varepsilon_k^2]$




$$H_r(f) = \frac{p_1 p_2}{(s+p_1)(s+p_2)}$$

$$n_0 = 4kTR\int_{-\infty}^{\infty} |H_r(f)|^2\, df$$



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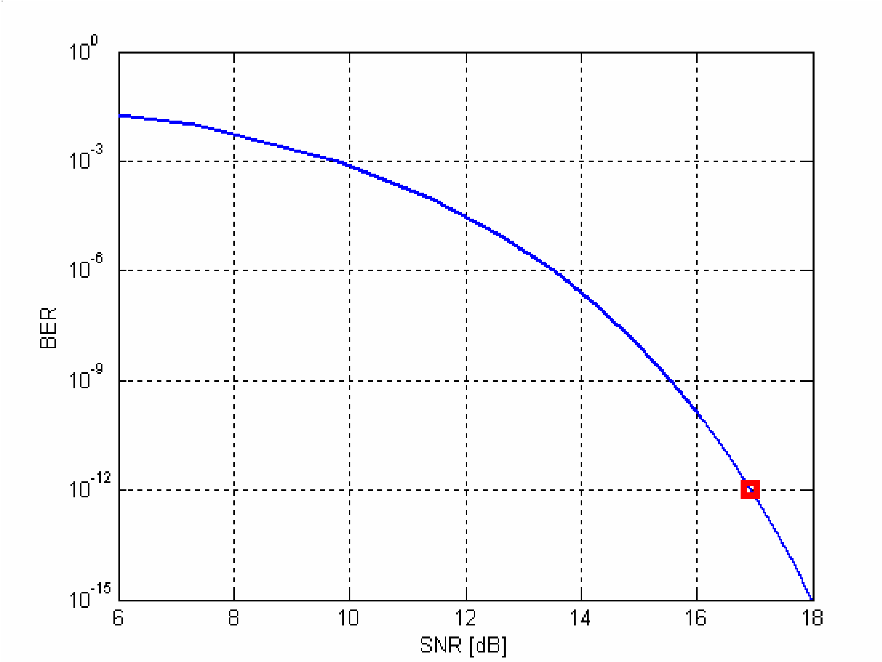
# Simulation Results

# Target SNR

- SNR must be better than 17 dB to achieve a BER $\leq$ 1E-12.
- This relationship assumes that the noise term is Gaussian.
- This is an upper bound on the BER when the noise term is not truly Gaussian.
  - For example, residual ISI and crosstalk





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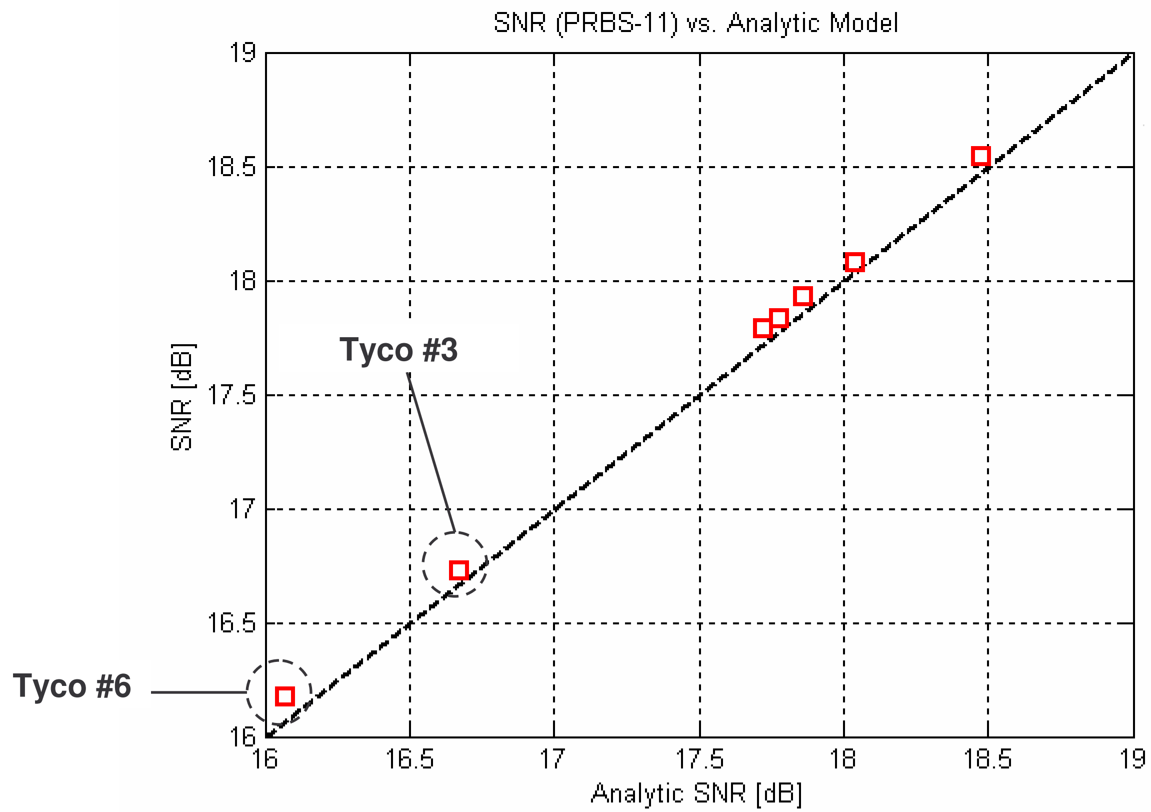
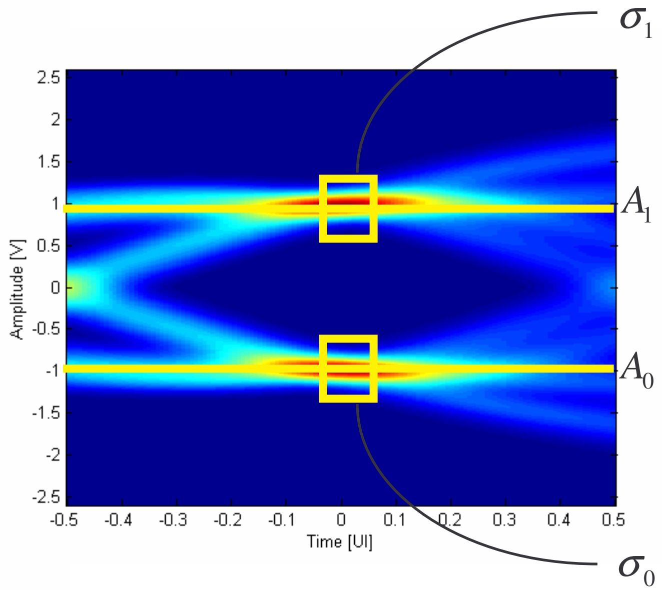
# SNR Correlation




$$SNR = \frac{A_1 - A_0}{\sigma_1 - \sigma_0}$$



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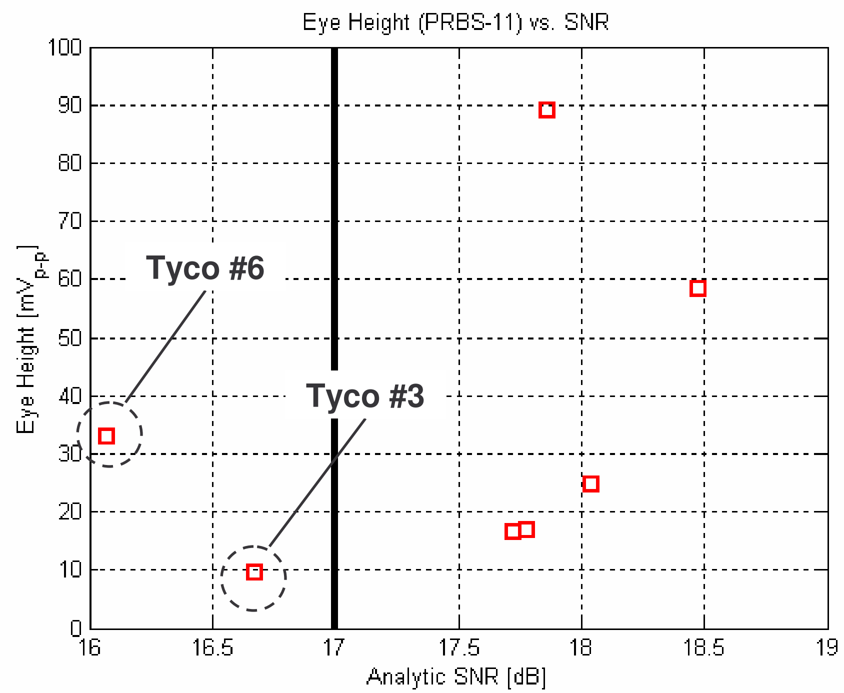
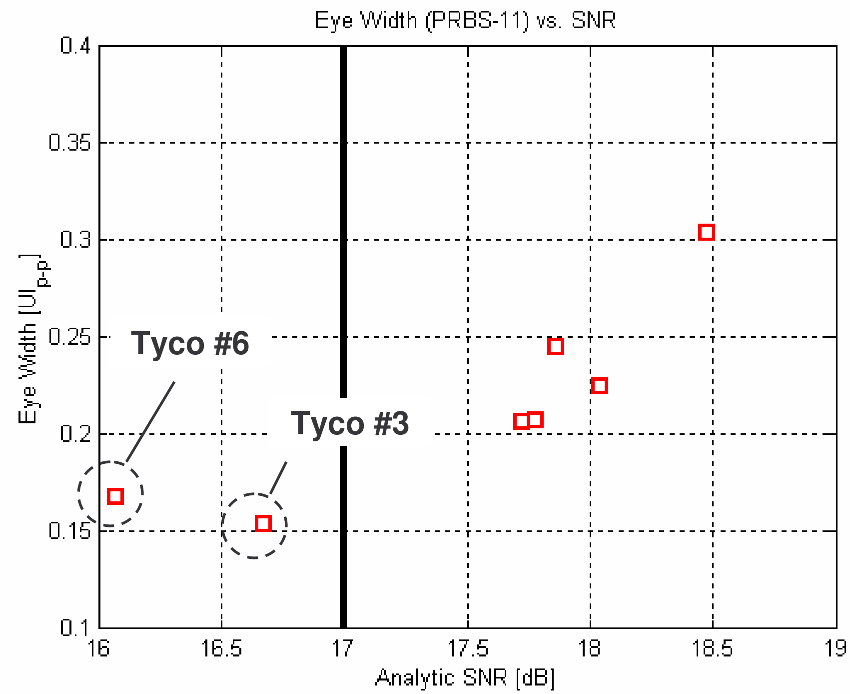
# SNR Correlation to Eye Height and Width



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# Observations

- Analytic model predicts SNR quickly and accurately.
- Analytic model does not accurately predict eye height and width.
  - This is more a commentary on the correlation of SNR to height and width.
  - Comparisons were made using PRBS-11 pattern; a longer pattern would result in degradation of both eye height and width.
- Analytic model is pessimistic.
  - Requirements derived from this model should be more than sufficient for target applications.


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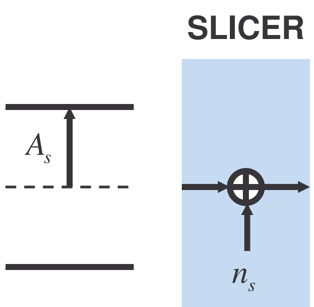
# Sensitivity Requirement Estimate

- $Q_i$ is the SNR at the slicer input
- $A_s$ is the slicer sensitivity
- $Q_0$ is the target SNR (based on BER objective)
- If $Q_i \le Q_0$, then $A_s = 0$.




$$A_i = \frac{G_0}{\sum_m |c_m|} \qquad n_i = \frac{G_0}{Q_i \sum_m |c_m|}$$

$$A_s = Q_0 n_s$$

$$A_i \ge Q_0 \sqrt{n_i^2 + n_s^2}$$

$$n_s \le \sqrt{\frac{A_i^2}{Q_0^2} - n_i^2}$$

$$n_s \le \frac{G_0}{\sum_m |c_m|} \sqrt{\frac{1}{Q_0^2} - \frac{1}{Q_i^2}}$$

$$\boxed{A_s \ge \frac{G_0}{\sum_m |c_m|} \sqrt{1 - \frac{Q_0^2}{Q_i^2}}}$$



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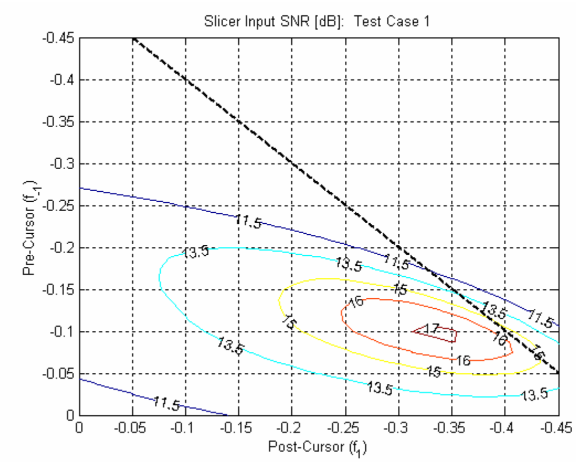
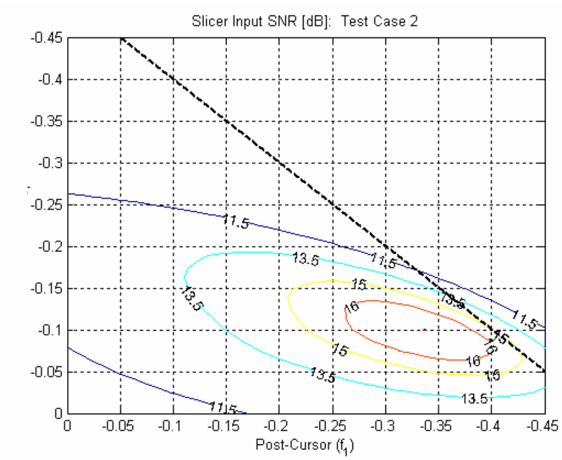
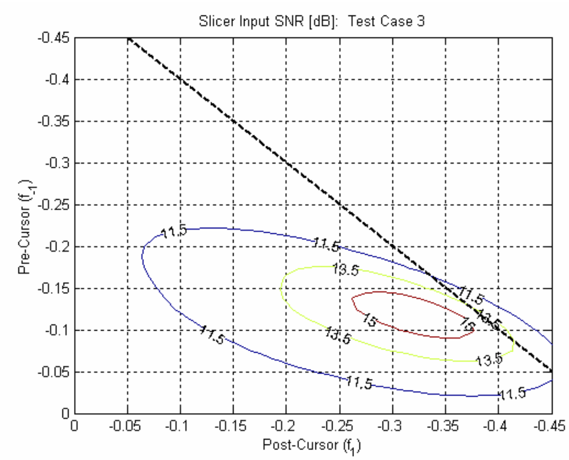
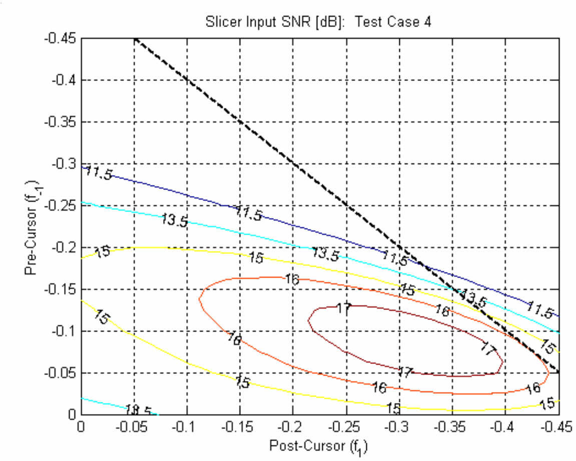
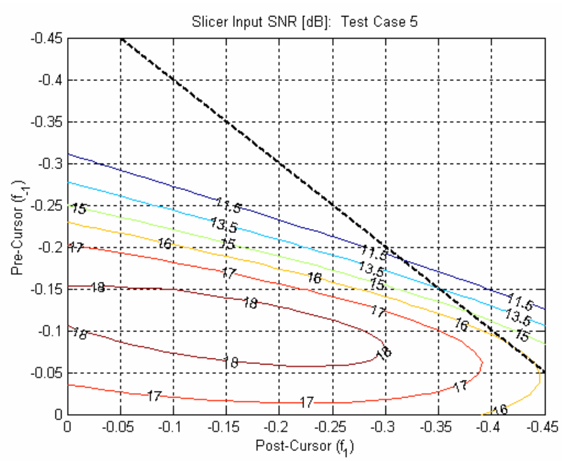
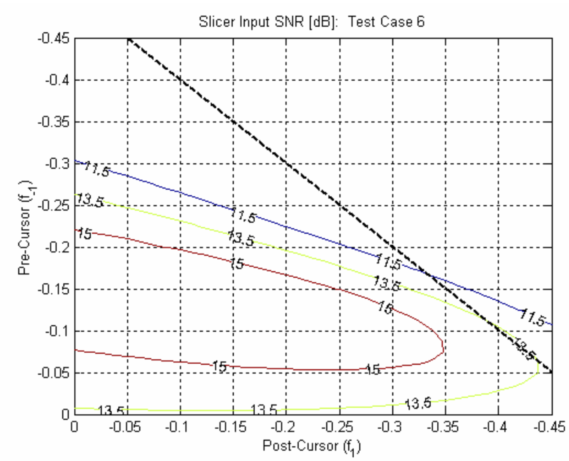


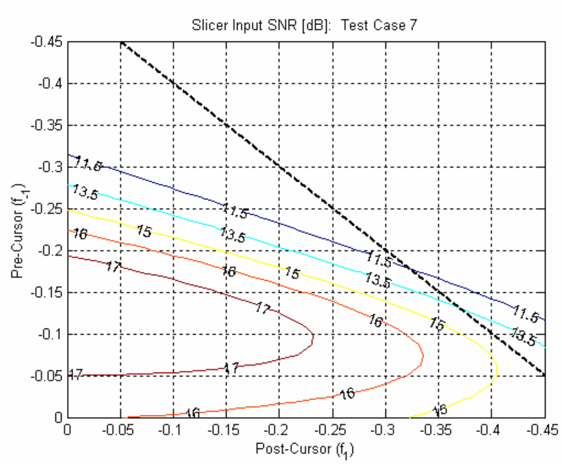



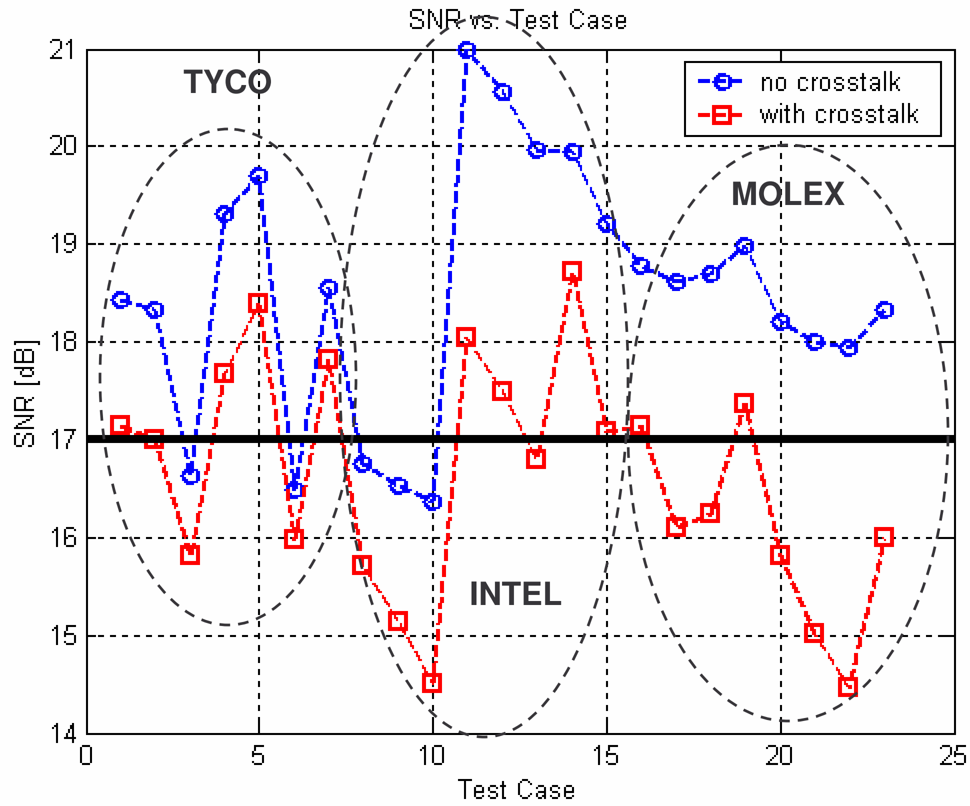




<u>Sample Results</u>

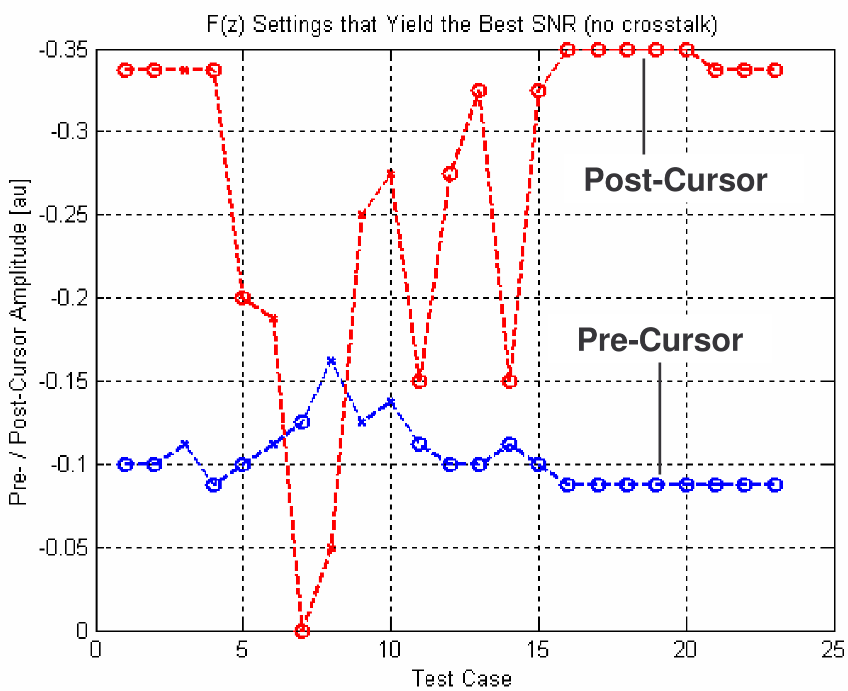
Tyco Test Cases

(with crosstalk)

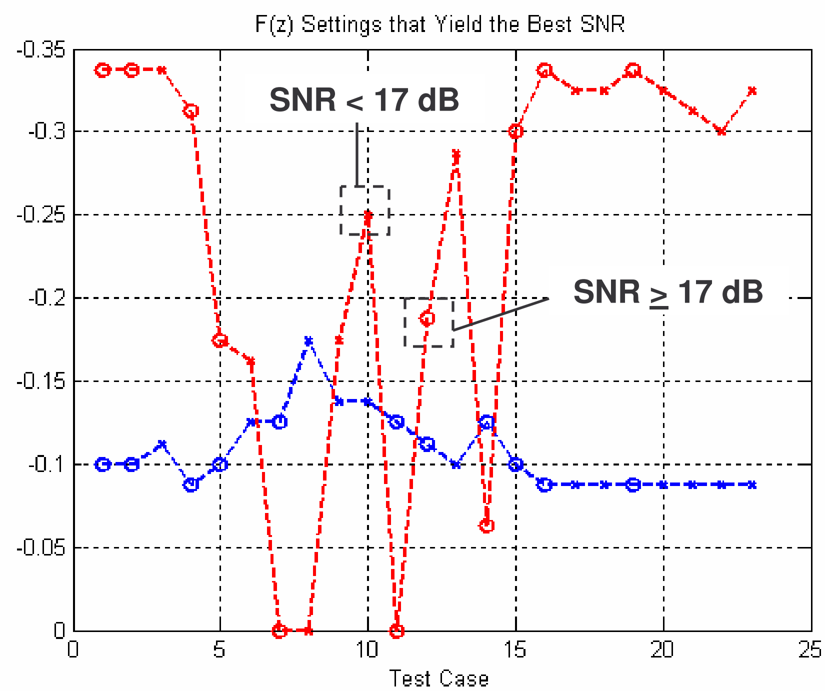
# SNR Results Summary



# Tap Weight Range

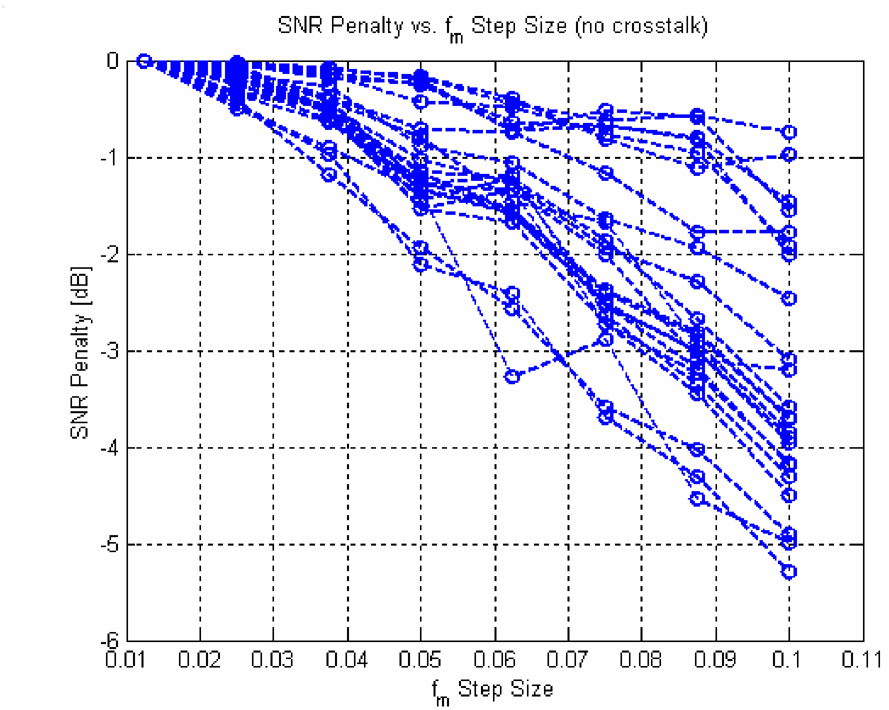


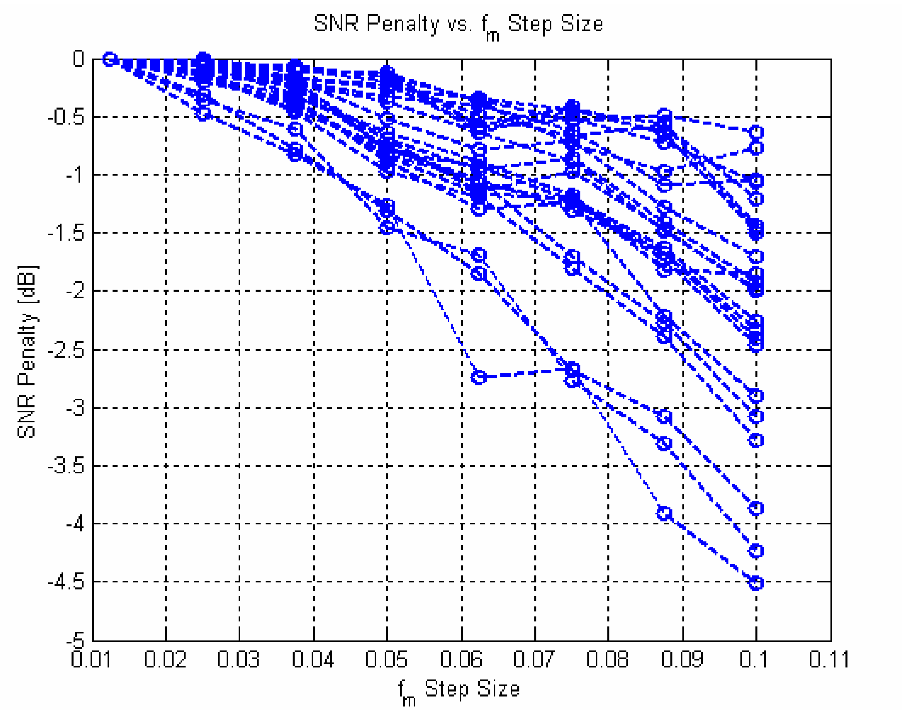

**No Crosstalk**




**With Crosstalk**

# Tap Weight Resolution (SNR Penalty)




**No Crosstalk**

**With Crosstalk**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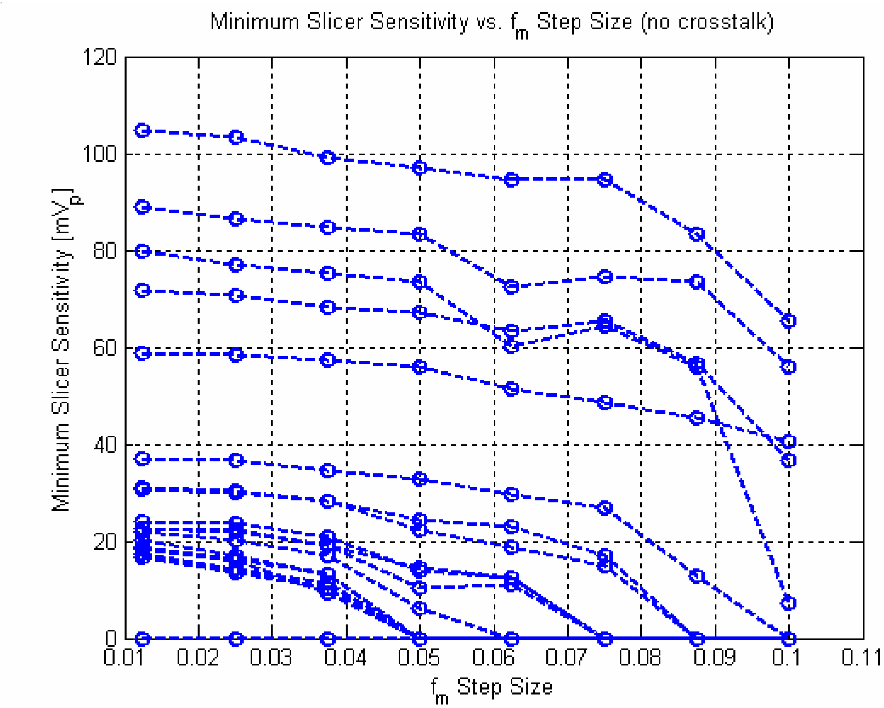
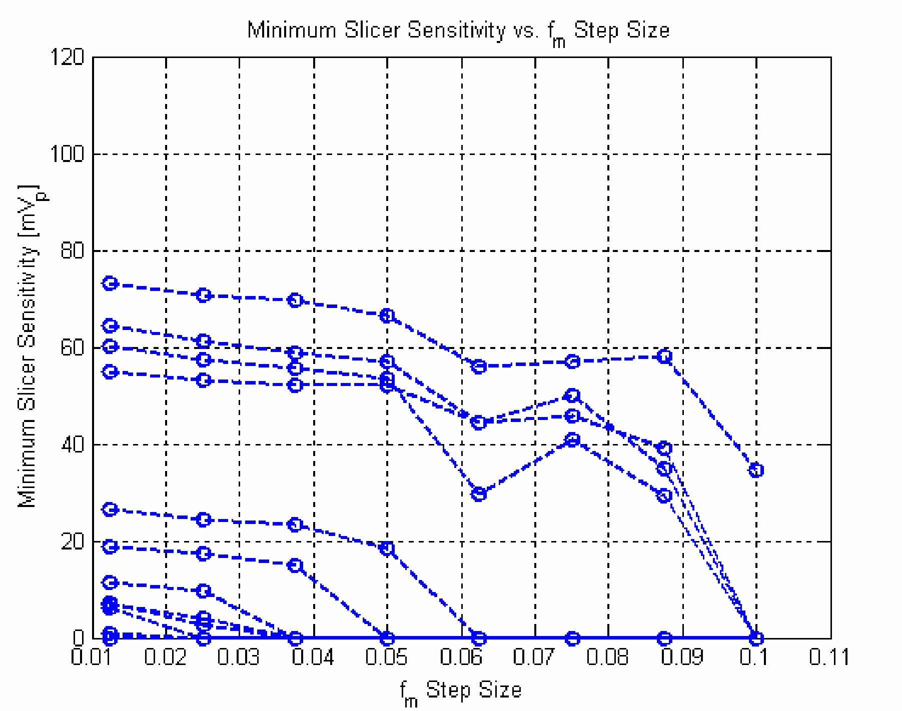
# Tap Weight Resolution (Sensitivity)




**No Crosstalk**

**With Crosstalk**



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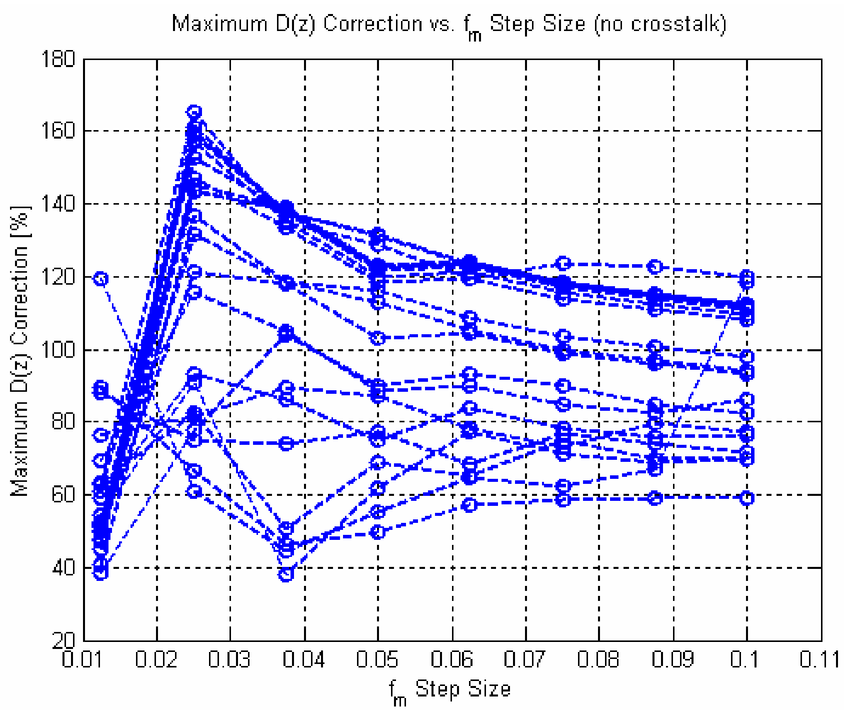
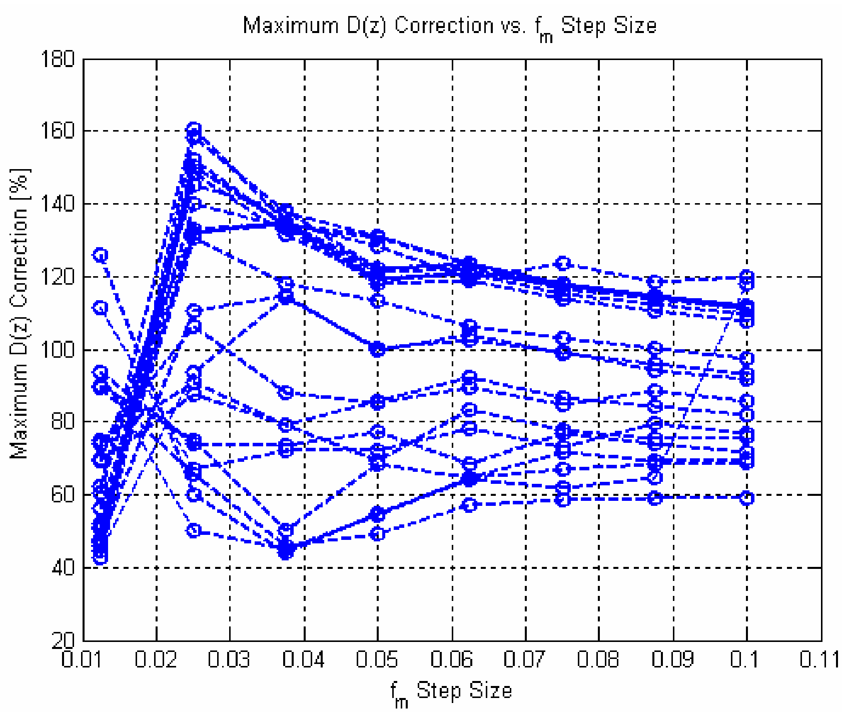
# Transmit Equalizer Impact on DFE




**No Crosstalk**

**With Crosstalk**

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# Conclusions

# Observations

- Required pre-cursor range is roughly half of the required post-cursor range.
- Crosstalk environment is a factor in determining the best transmit equalizer configuration.
  - In addition, more precise equalization is required to provide more "headroom" in higher crosstalk environments.
- Link performance decreases with decreasing transmit equalizer resolution.
- Demands on the DFE receiver increase with decreasing transmit equalizer resolution.

# Recommendations

- Define no fewer than 16 post-cursor settings in the range of –0.375 to 0
  - Post-cursor step size is 0.025
- Define no fewer than 8 pre-cursor settings in the range of –0.175 to 0
  - Pre-cursor step size is 0.025
- Define the pre- and post-cursor tolerance to be +/- 0.0125
- This would correspond to 128 possible transmit equalizer "states"

## Future Work

- Investigate “sensitive” test cases with a detailed voltage and timing margin analysis.
- Are positive post-cursor tap weights required?
  - Such scenarios are conceivable with reflections.