PAM-N Tutorial Material

802.3bj 100 Gb/s Backplane and Copper Cable Task Force

IEEE 802.3 Plenary Session

Waikoloa, HI

12-15 March 2012

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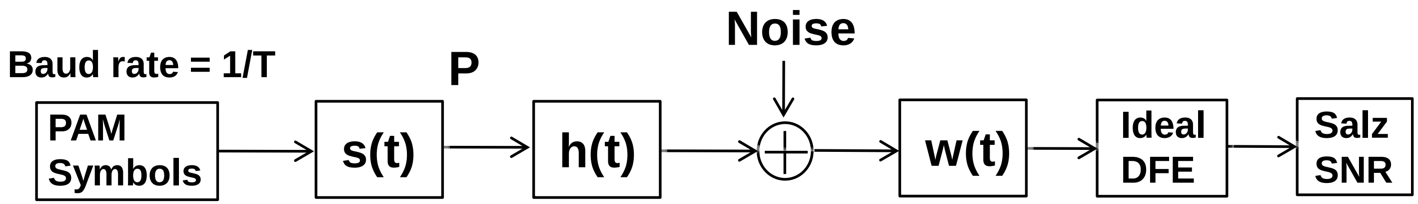
Outline

- Salz SNR Formula for AWGN Channel
- Salz SNR Formula for Xtalk Channel
- Summary Results
- Conclusions

Salz SNR Model for AWGN Channel



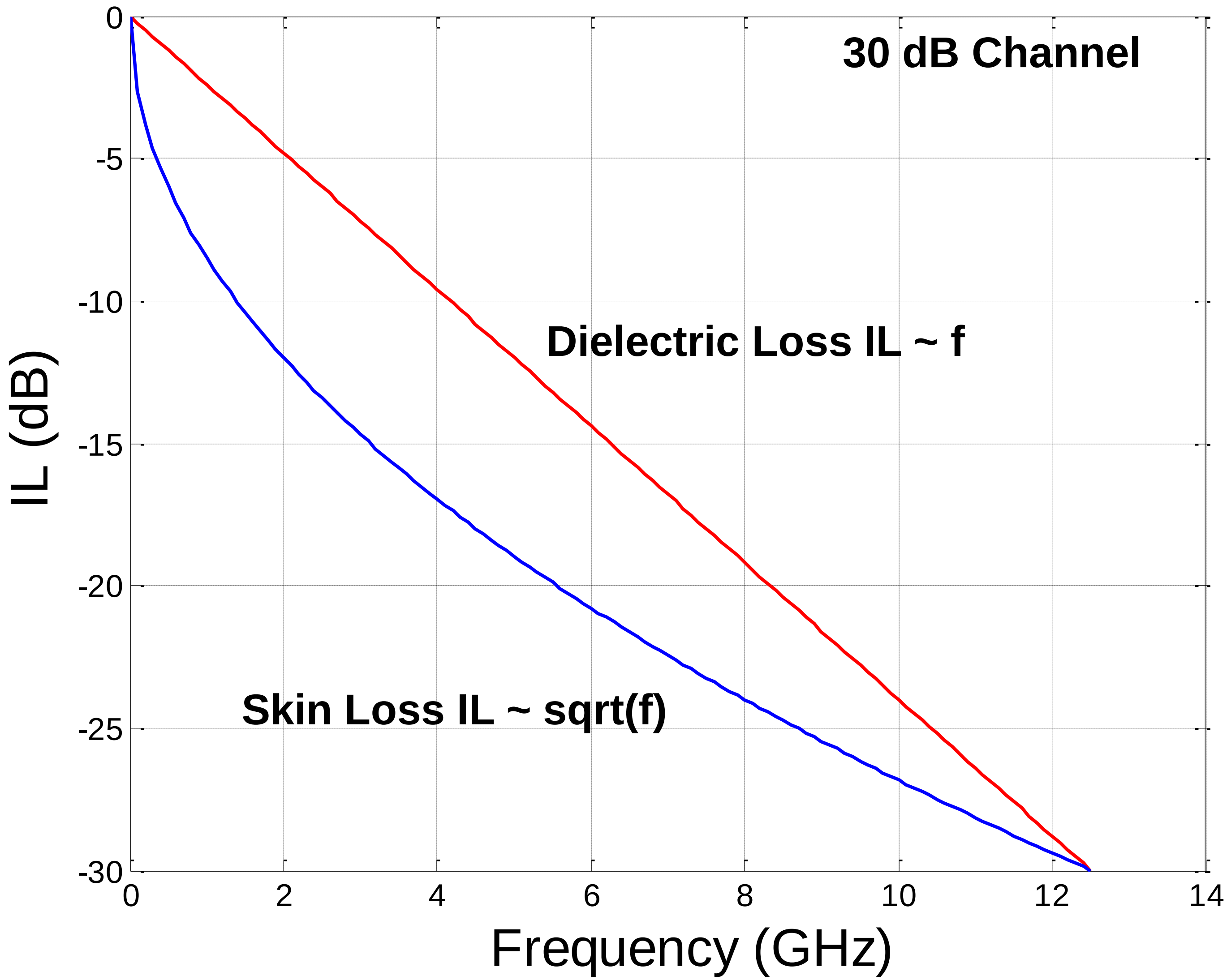
$$SNR = e^{\left[2T\int_0^{\frac{1}{2T}} \ln\left(Y(f)+1\right)df\right]} = e^{\frac{1}{f_{NY}}\int_0^{f_{NY}} \ln\left(Y(f)+1\right)df}$$

$$Y(f) = \rho\left|H(f)\right|^2$$

ρ = Tx SNR

$$IL(f) = 10Log10\left(\left|H(f)\right|^2\right)$$

Channel Insertion Loss Models



SNR Formula

In the limit of high TX SNR, Taylor series expansion results in a simple Salz SNR Formula.

Dielectric loss:

$$SNR_{dB} = \rho_{dB} - \frac{1}{2}(IL_{f_{NY}})$$

Skin loss:

$$SNR_{dB} = \rho_{dB} - \frac{2}{3}(IL_{f_{NY}})$$

IL is evaluated at the Nyquist frequency of each modulation format.

SNR Formula cont.

Salz SNR Formula as a function of IL at NRZ Nyquist:

Dielectric loss:

$$SNR_{dB}^{NRZ} = \rho_{dB} - \frac{1}{2} IL$$

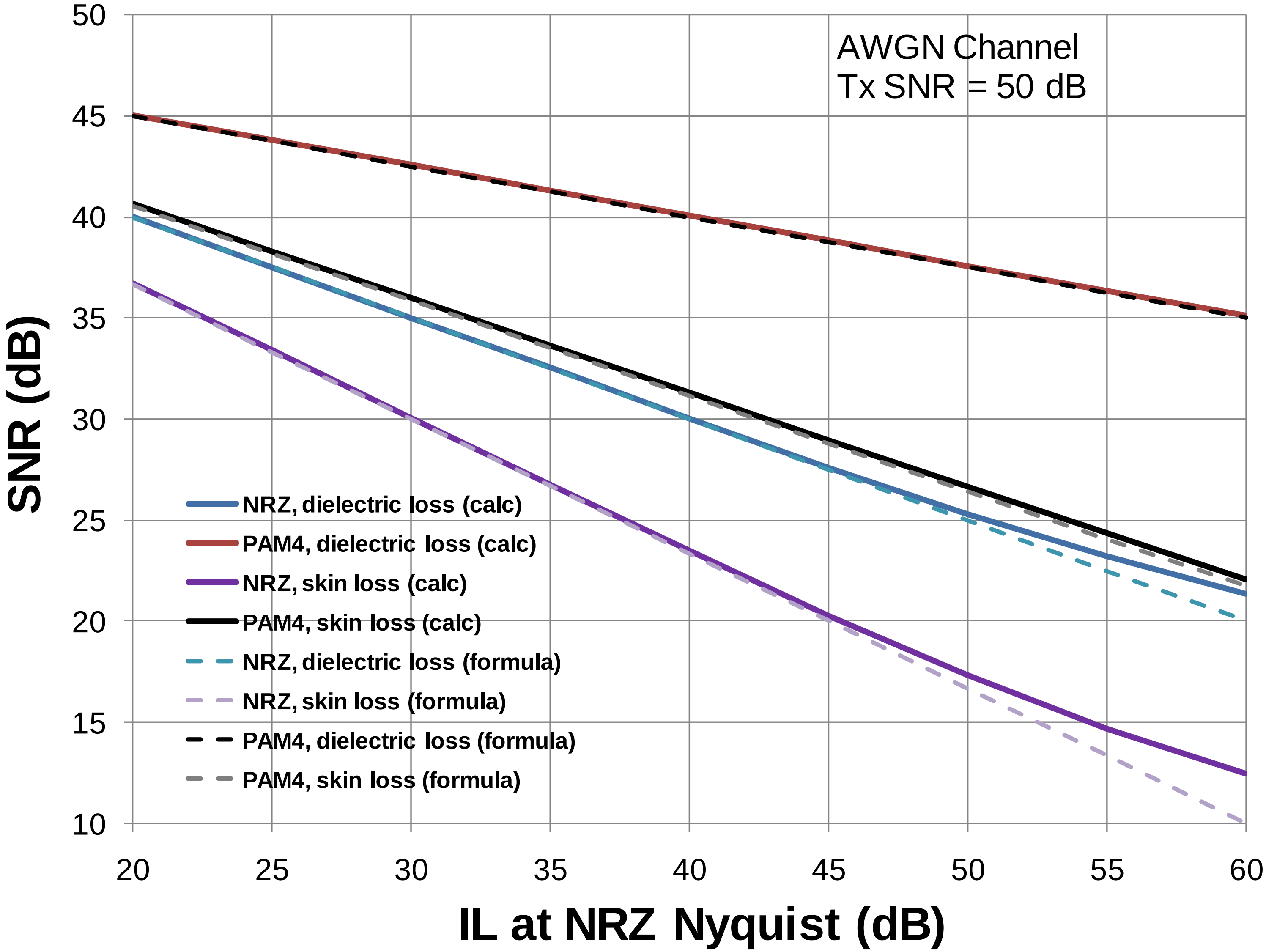
$$SNR_{dB}^{PAM4} = \rho_{dB} - \frac{1}{4} IL$$

Skin loss:

$$SNR_{dB}^{NRZ} = \rho_{dB} - \frac{2}{3} IL$$

$$SNR_{dB}^{PAM4} = \rho_{dB} - \frac{\sqrt{2}}{3} IL$$

SNR Formula & Numeric Calc Comparison



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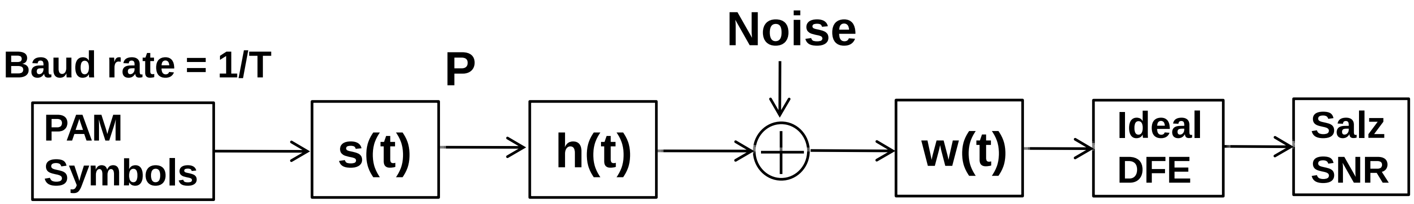
Salz SNR Model for Colored Noise



$$SNR = e^{\left[2T \int_0^{\frac{1}{2T}} \ln\left(Y(f)+1\right) df \right]} = e^{\frac{1}{f_{NY}} \int_0^{f_{NY}} \ln\left(Y(f)+1\right) df}$$

$$Y(f) = \frac{P(f)}{N(f)} \left| H(f) \right|^2$$

P(f) = signal power spectral density
N(f) = noise power spectral density
Note when N(f) is due to Xtalk, then Y(f)=ICR(f)

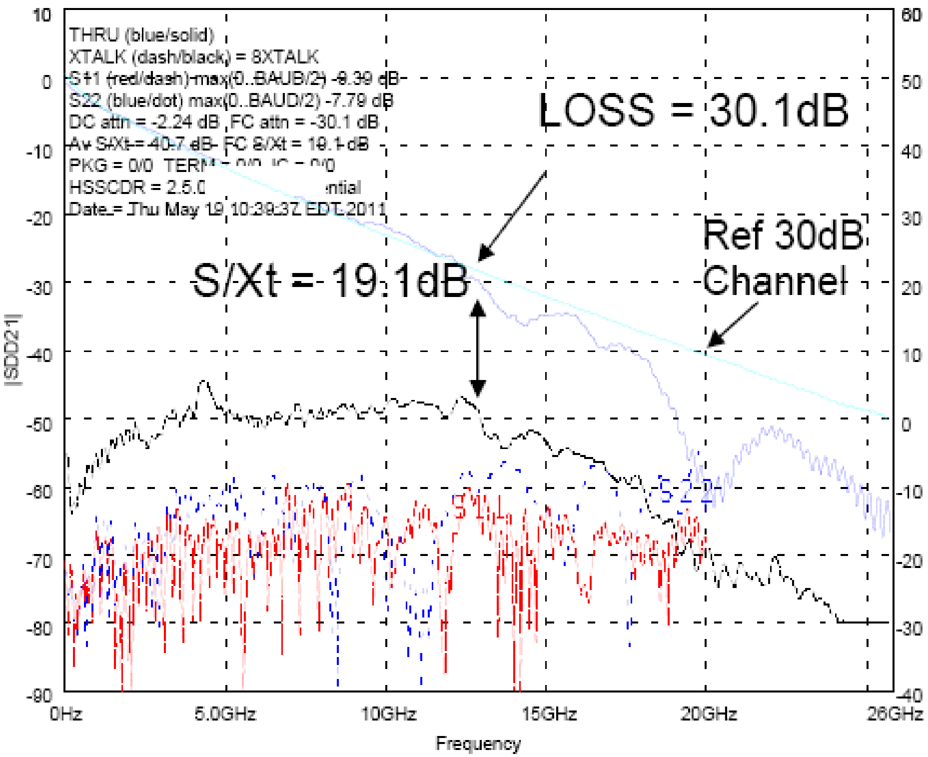
Salz SNR Model for Xtalk Channel

$$SNR_{dB} = \frac{1}{f_{NY}} \int_0^{f_{NY}} 10\log 10\left(Y(f)+1\right)df = \left\langle \left(Y(f)+1\right)_{dB} \right\rangle$$

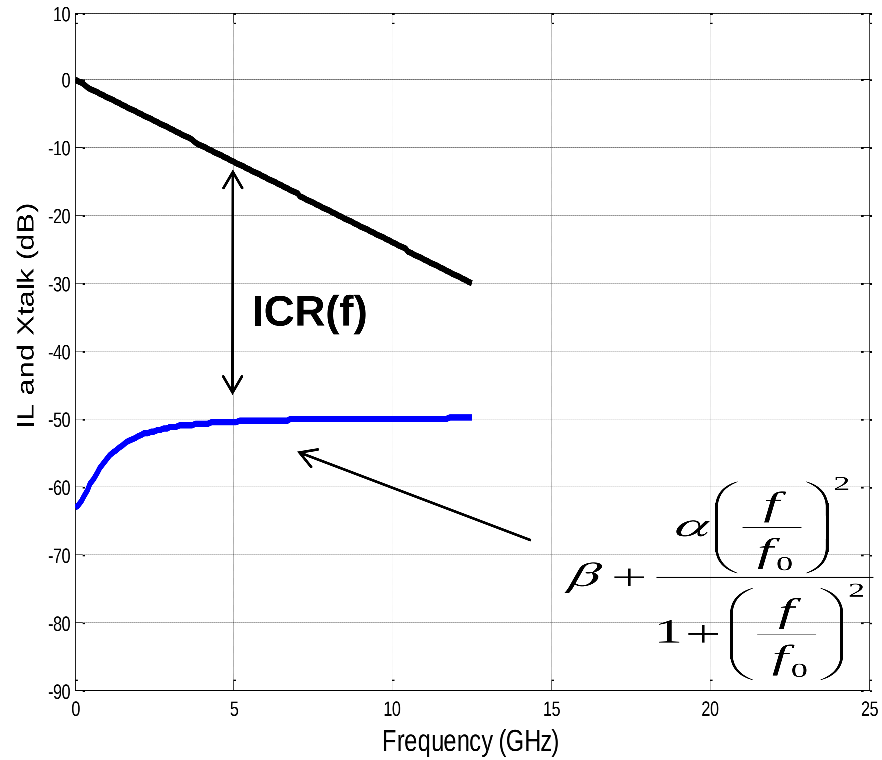
$$Y(f) = \frac{P(f)}{N(f)} \left|H(f)\right|^2 = ICR(f)$$

Xtalk Model Example

IBM measured 30 dB channel (beukema_01a_0911)



Xtalk Model



Model Parameters:

f_0=2GHz, α=1.e-5, β=5.e-7

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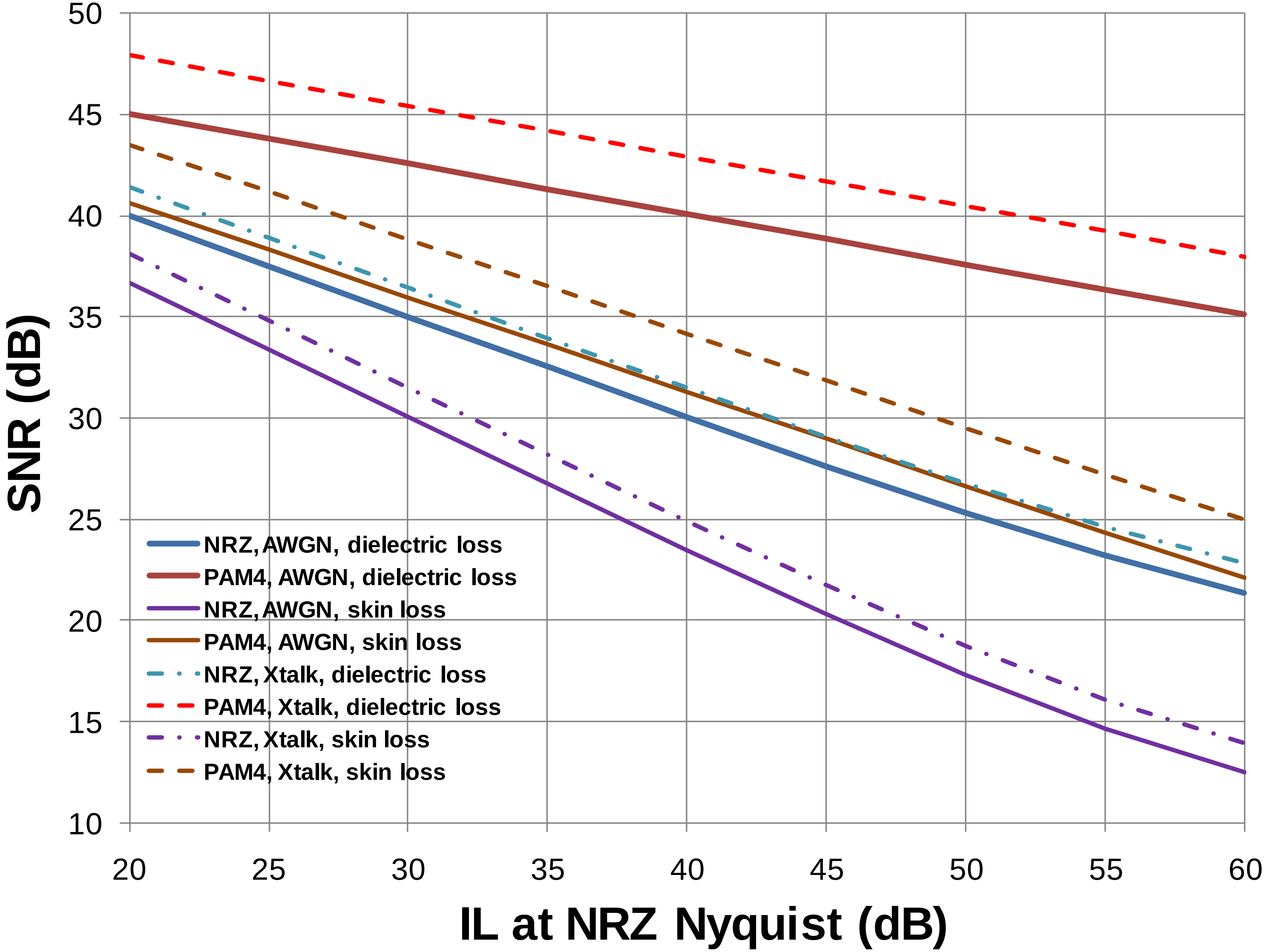
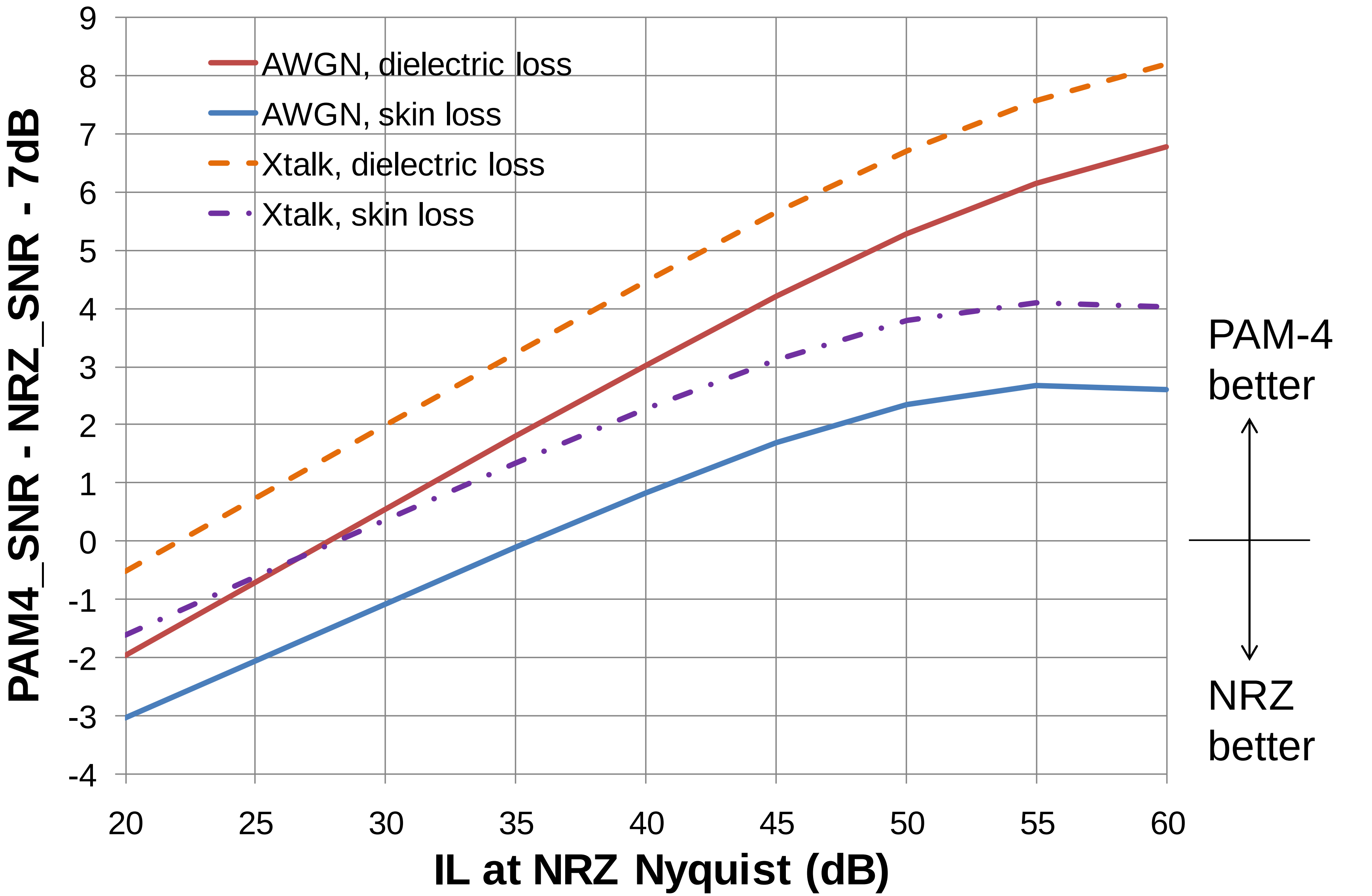
SNR Formula for AWGN & Xtalk Channels



ΔSNR Formula Comparing NRZ & PAM-4



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Conclusions

- Salz Formula for AWGN channel predicts better PAM-4 versus NRZ performance for:
  - $IL_{12.5GHz}$ > 28dB (dielectric loss limited channel)
  - $IL_{12.5GHz}$ > 35dB (skin loss limited channel)
- Salz Formula for Xtalk example channel predicts better PAM-4 versus NRZ performance for:
  - $IL_{12.5GHz}$ > 22dB (dielectric loss limited channel)
  - $IL_{12.5GHz}$ > 28dB (skin loss limited channel)