National Aeronautics and Space Administration

Action: Baseline Channel Model for SCCC-X and DVB-S2X

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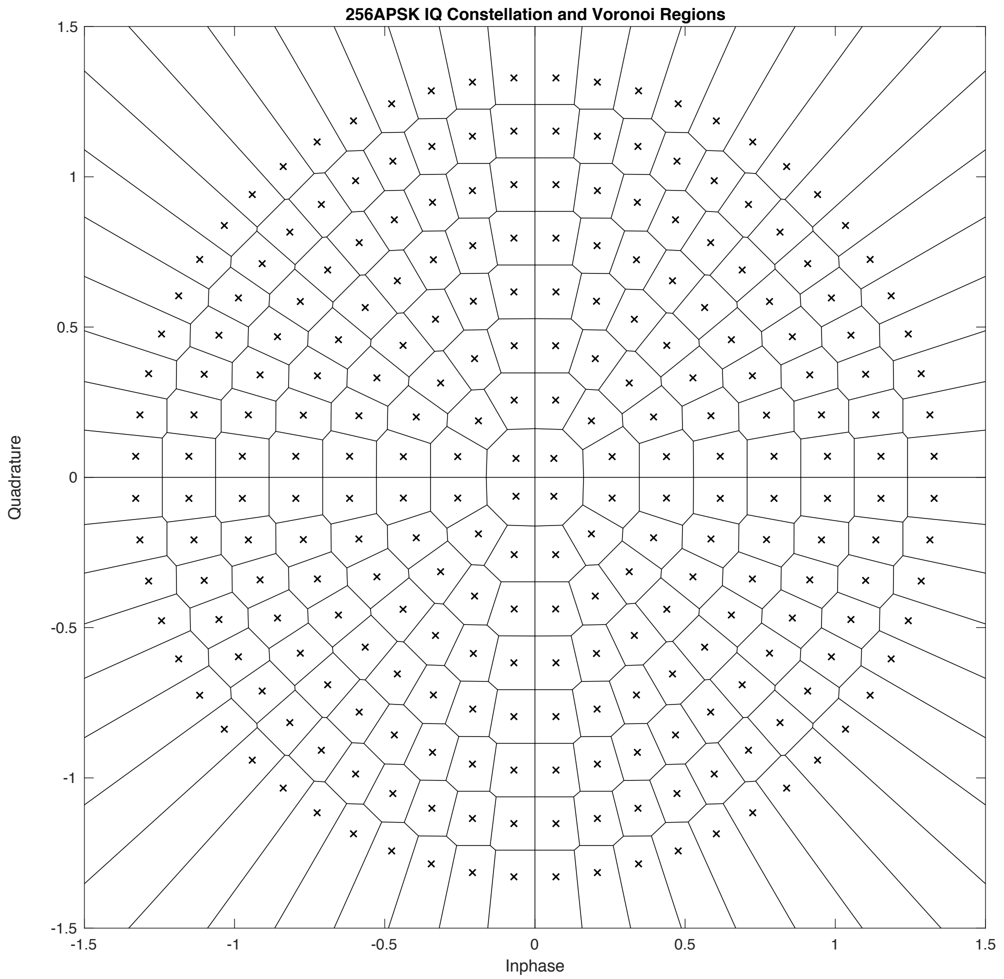
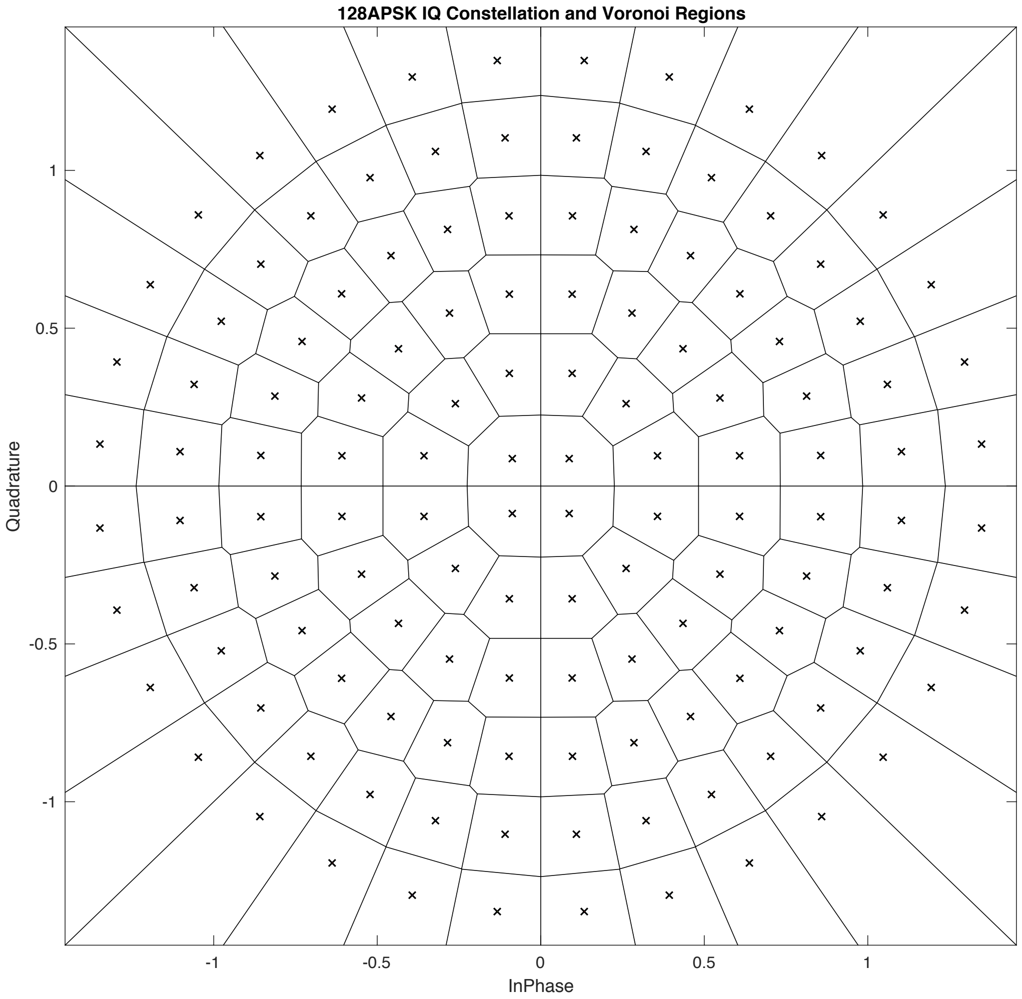
Background

- Intro
  - In the Fall of 2017 in Den Haag, CNES presented a concept paper, SLS-CS 17-07, to extend the set of modulations and coding options for the CCSDS 131.3-B-1, DVB-S2 Blue Book.
  - In the following Spring meeting 2018 in Gaithersburg, ESA presented SLS-CS 18-04, a similar proposal to extend the CCSDS 131.2-B-1, the SCCC Blue Book
  - **Goal: NASA/GSFC was directed to study and develop a minimal set of transmitter distortions to evaluate both proposals.**
- Objectives:
  - Review documents: SLS-RFM 09-09 “ESA advanced coding and modulation performance under realistic channel conditions”, CCSDS 130.12-G-1 CCSDS Protocols over DVB-S2, CCSDS 130.11-G-0 DRAFT SCCC - Summary of Definition and Performance for relevance.
  - Analyze through theory and simulations, the BER performance of 256APSK and 128APSK with channel distortions.
  - Develop a set of baseline distortion characteristics to evaluate the DVB-S2X and SCCC-X proposals based on analysis and simulations.

Theoretical Foundation

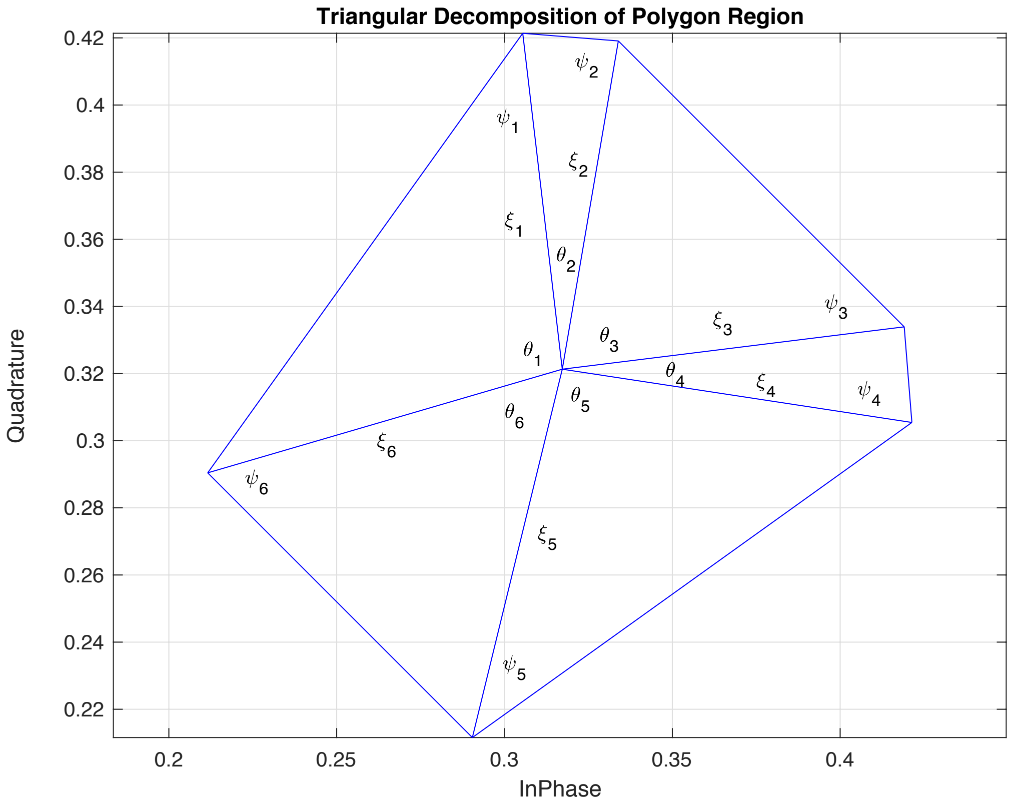
- Constellation Diagram and Voronoi Regions for SCCC-X





Theoretical Foundation(2)

- Predicting BER performance



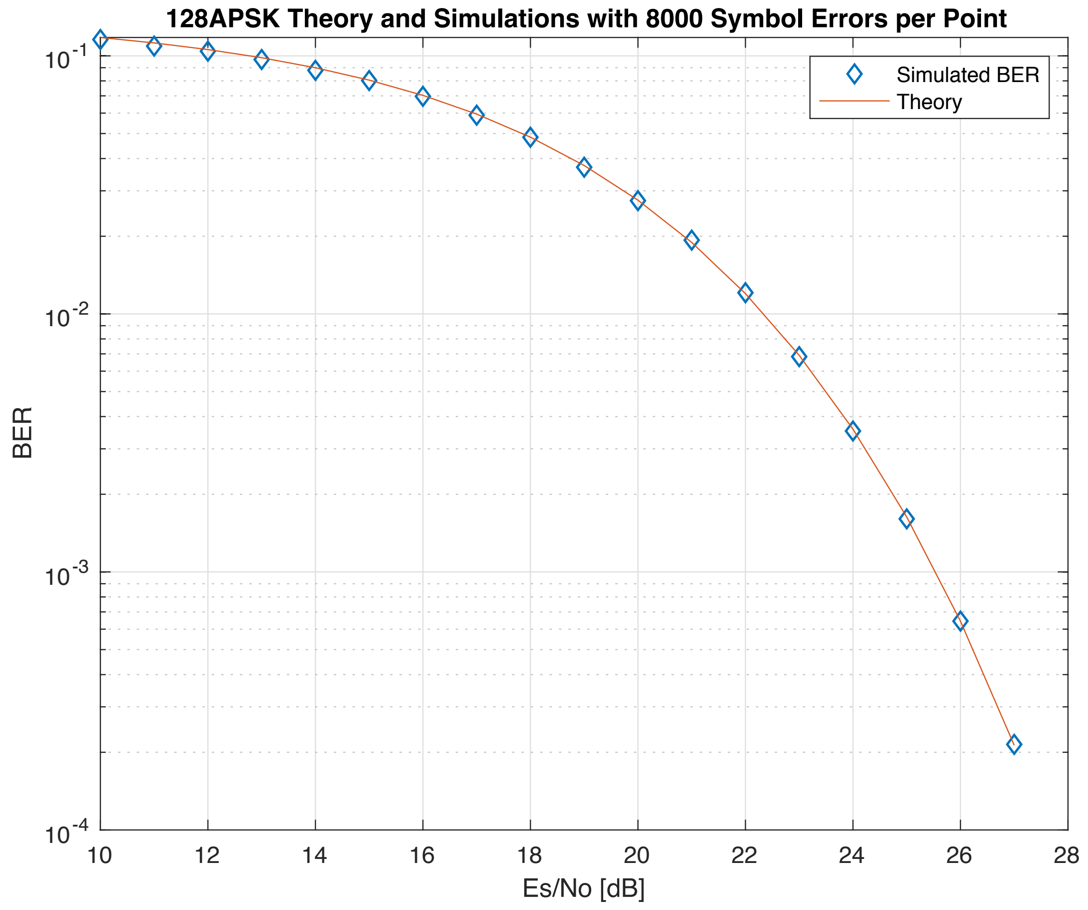
$$P_{e,l} = \frac{1}{2\pi} \sum_{k=1}^{K^{\{l\}}} \int_0^{\theta_k^{\{l\}}} \exp\left(- \frac{\xi_k^{\{l\}2} \sin^2(\psi_k^{\{l\}})}{2\sigma^2 \sin^2(\theta + \psi_k^{\{l\}})} \right) d\theta$$

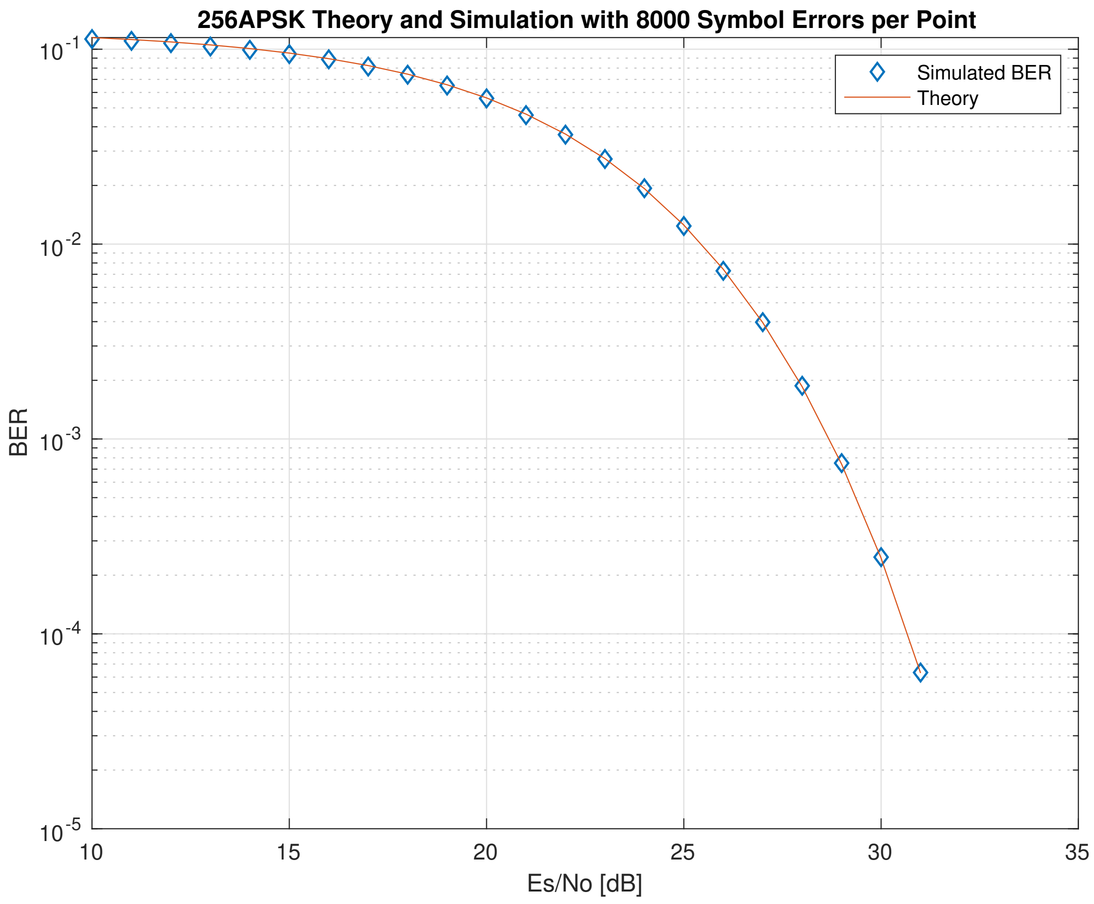
$$P_e = \sum_1^N \frac{P_{e,l}}{N}$$

$$P_b \approx \frac{1}{\log_2 N} P_e$$

Theoretical Foundation(3)

- Predicting BER performance





Phase and Amplitude Imbalance

$$C1 = (1 + \Gamma \exp(-j\Phi))/2$$
$$C2 = (1 - \Gamma \exp(-j\Phi))/2$$

angle imbalance Φ

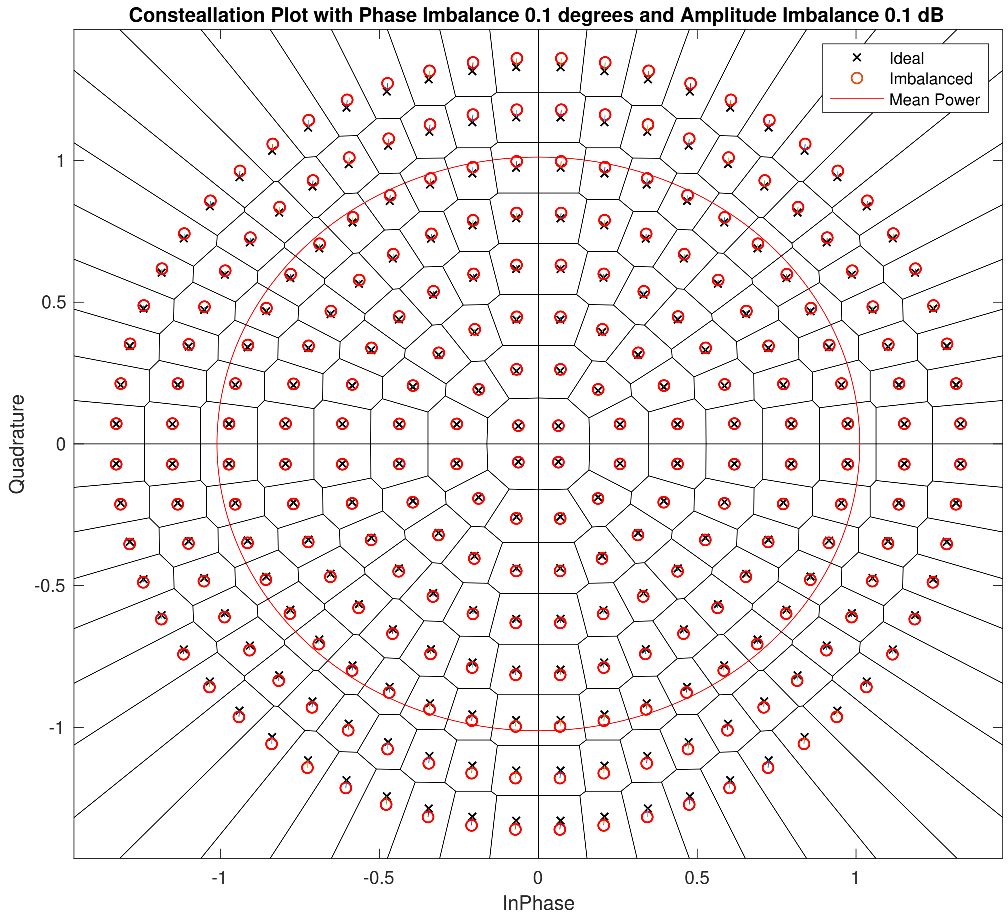
amplitude imbalance Γ

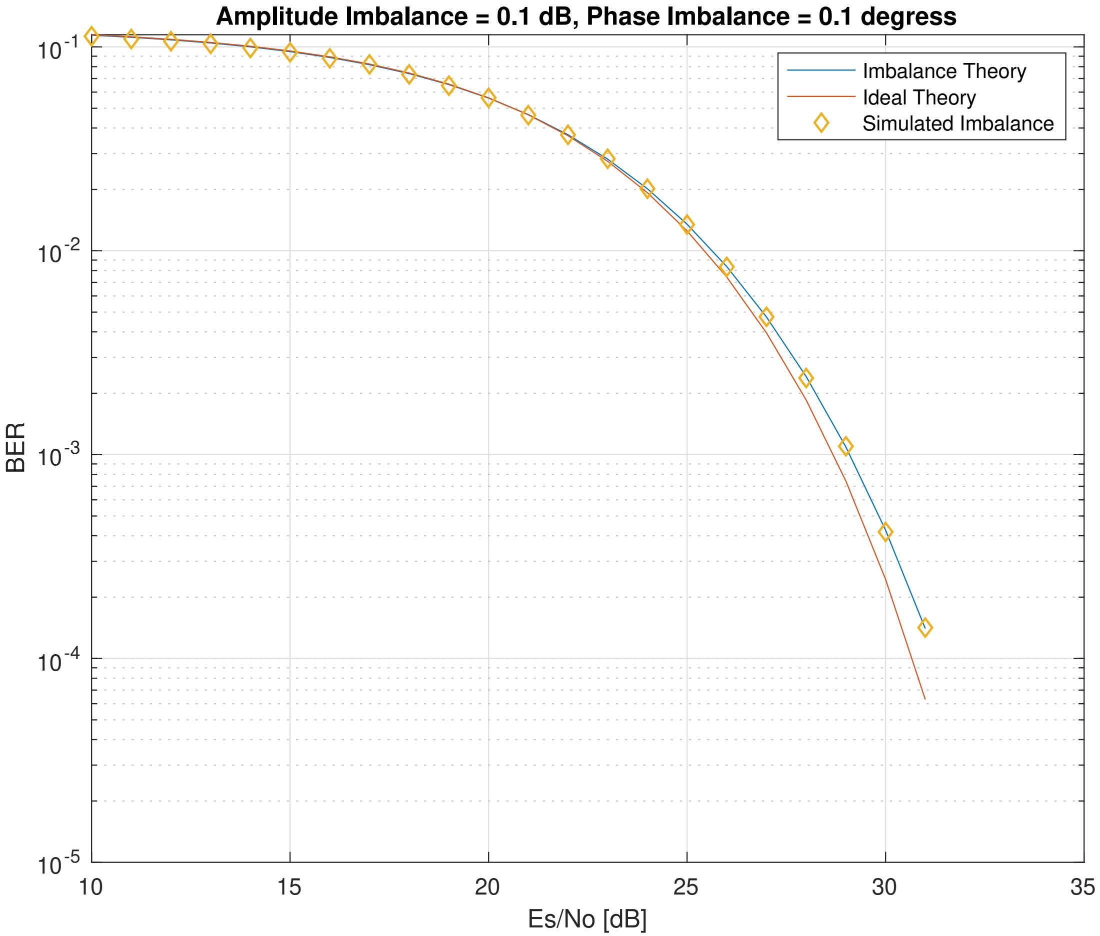
$$Y = C1 \cdot X + C2 \cdot X^*$$

Y defines the set of constellation points with I/Q imbalance

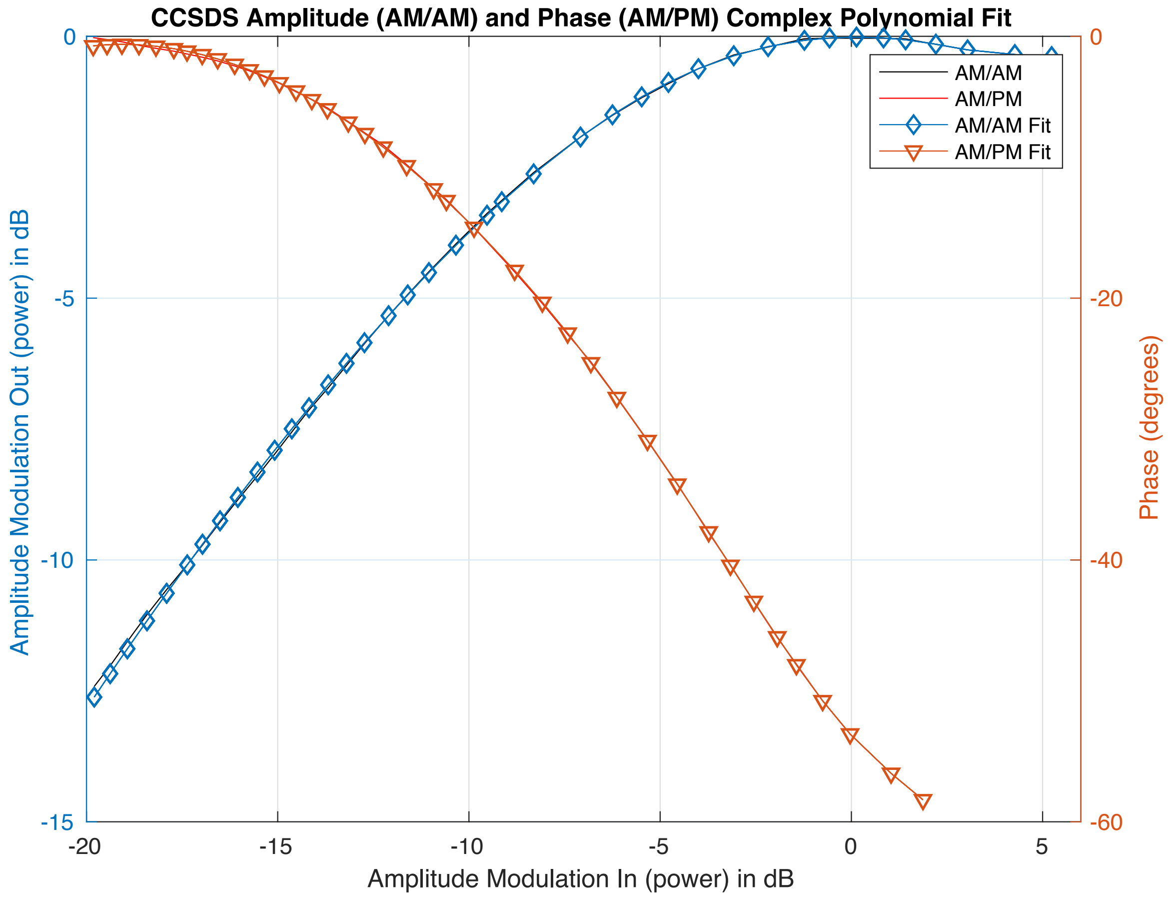
X defines the set of constellation points in complex values

Phase and Amplitude Imbalance(2)





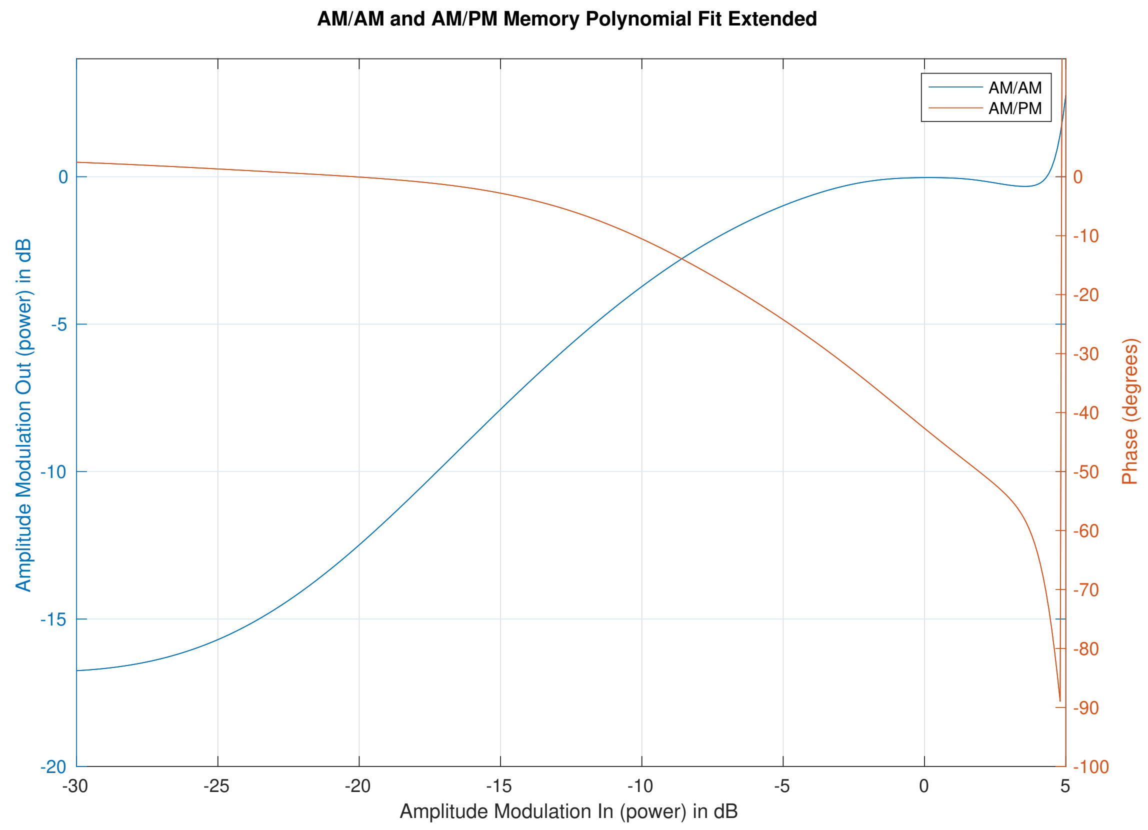
Non-linear Distortions



$$f(n) = \sum_{k=1}^{K} \sum_{q=0}^{Q} a_{kq} x(n-q) |x(n-q)|^{k-1}$$

$$f(n) = \sum_{k=1}^{K} a_k x(n) |x(n)|^{k-1}$$

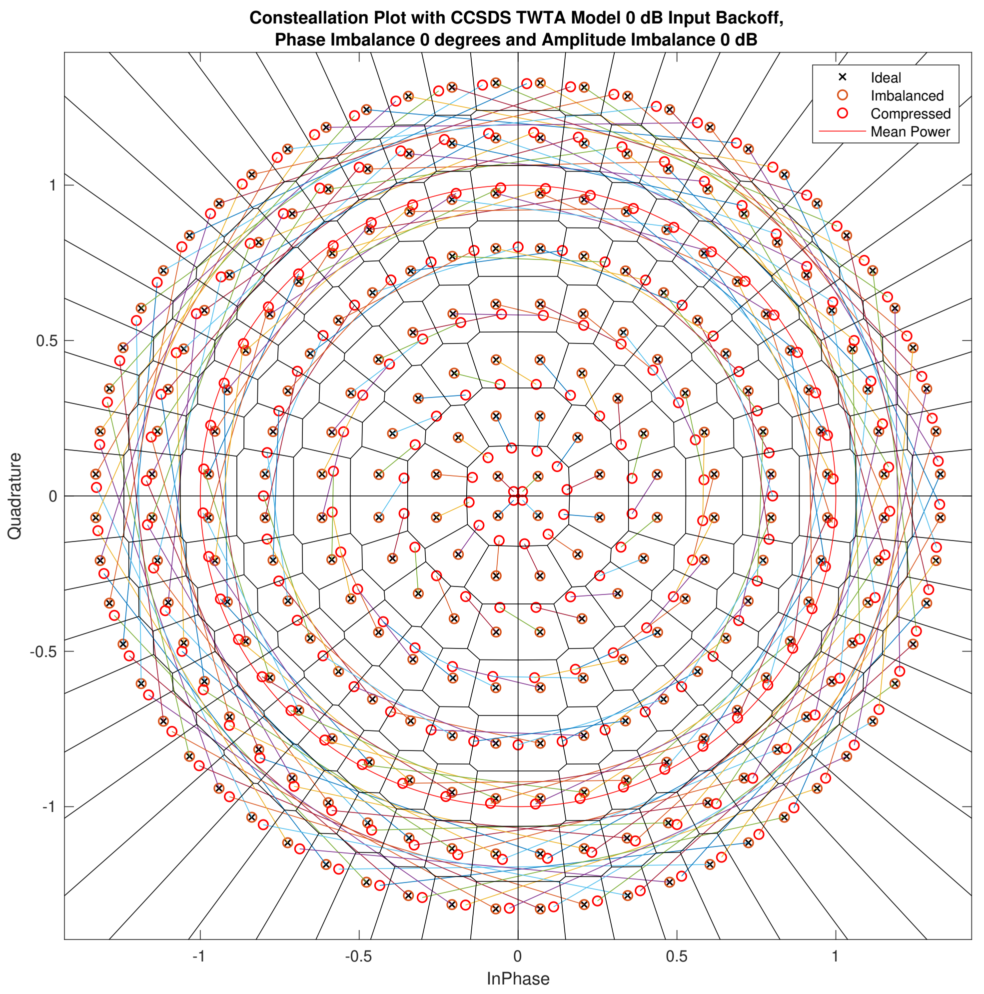
Non-linear Distortions(2)

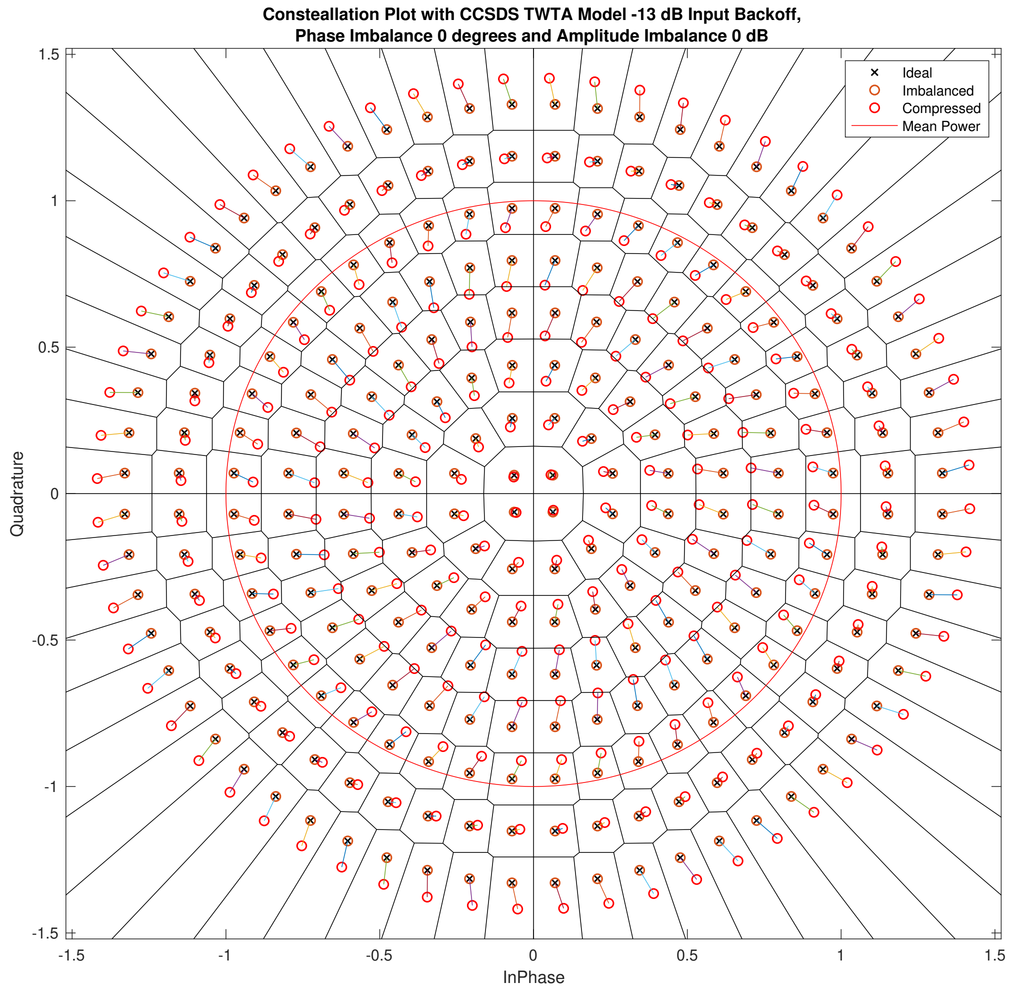


Complex Memory Polynomial Coefficients: a_k
0.168219331188666 + 0.0108707027652633i
-1.90396419138291 - 0.172928588413047i
44.4980770985467 + 0.621184506201673i
-257.130730617467 + 11.7256819339566i
897.304215044059 - 178.692731323500i
-2070.99561499126 + 750.801997897041i
3010.07199352395 - 1512.61874985406i
-2146.92499436427 + 1389.92271298938i
-695.429406871075 + 170.631105923232i
2782.84747075165 - 1626.18059517225i
-1542.20595666305 + 1069.12047494355i
-1639.74798152804 + 885.586789437163i
3380.30494836889 - 2057.00084143893i
-2733.47576088479 + 1712.04093333675i
1284.74818382355 - 815.403557197373i
-366.353360080971 + 234.220978480231i
59.1209847713142 - 37.9719767396993i
-4.16336885230580 + 2.68312358970457i

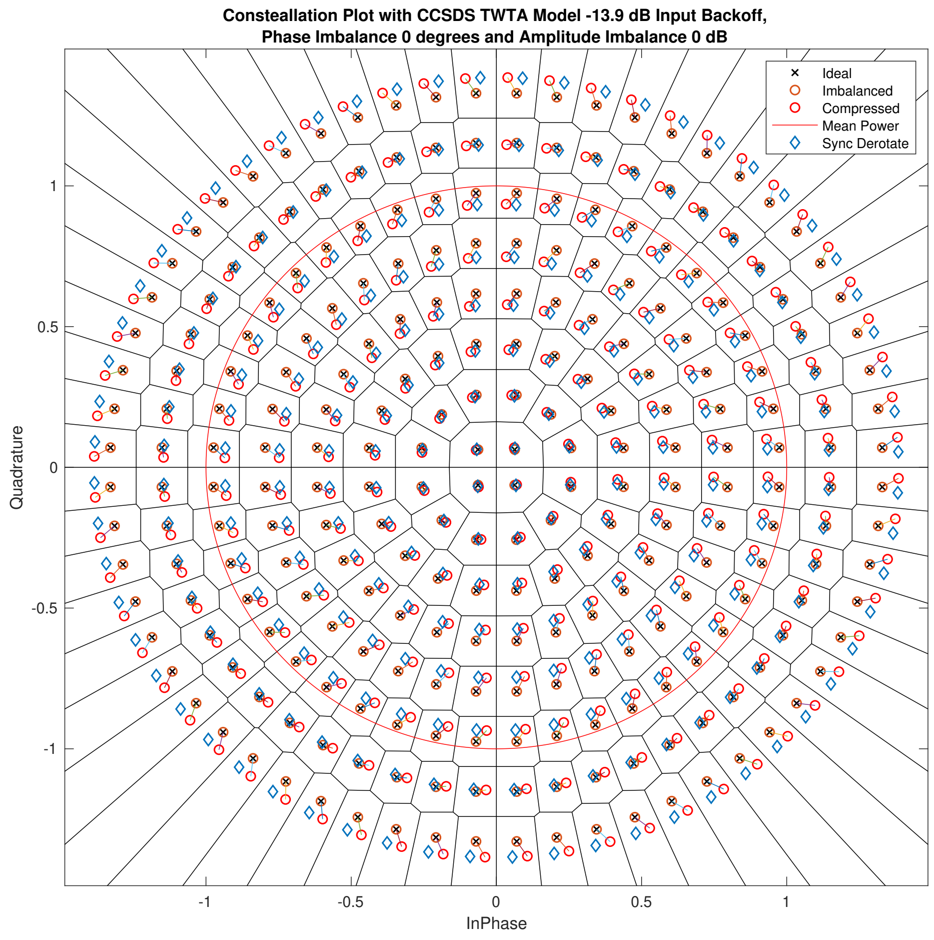
Table 1: 18 Complex Coefficients

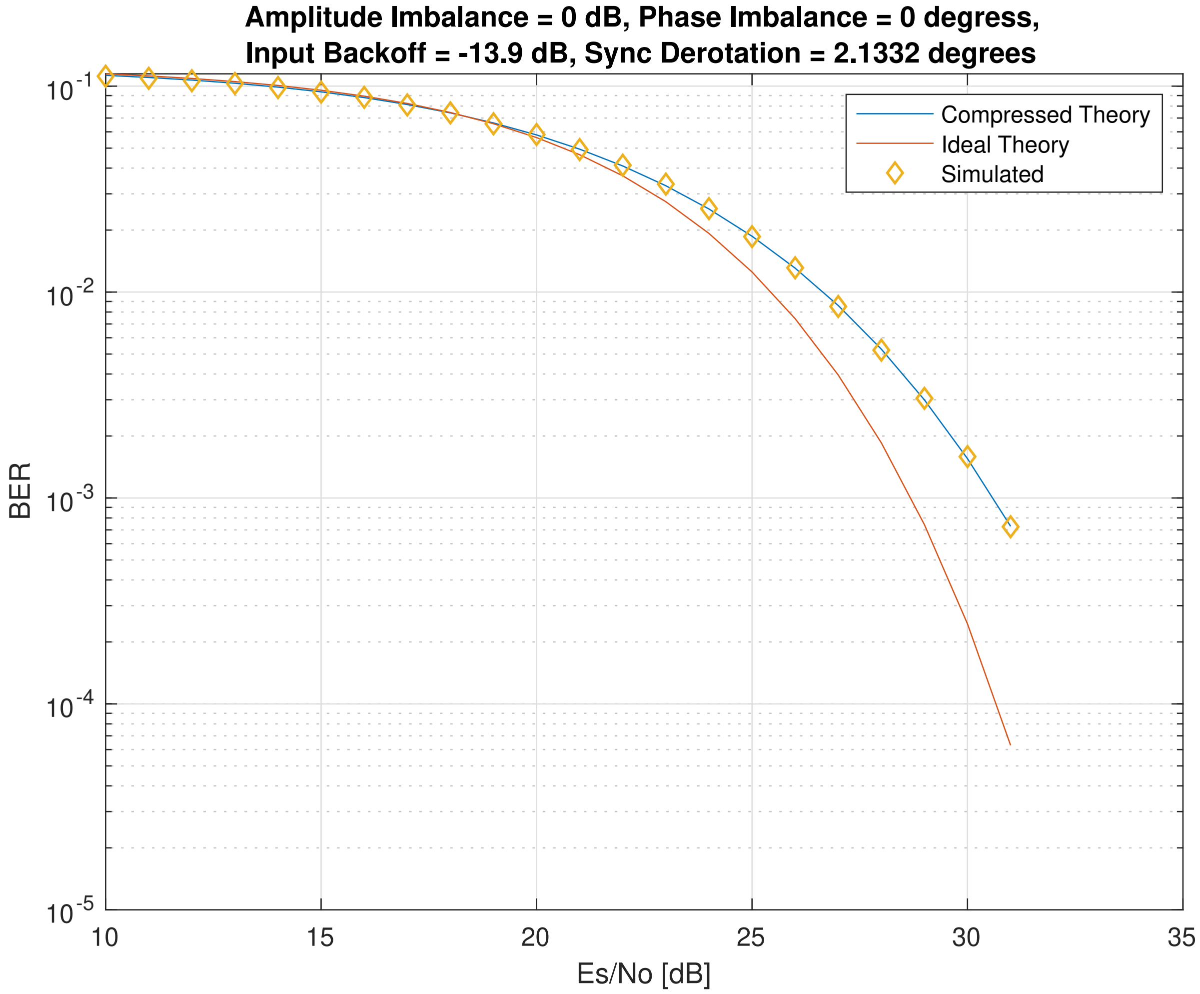
Non-linear Distortions(3)





Non-linear Distortions(4)

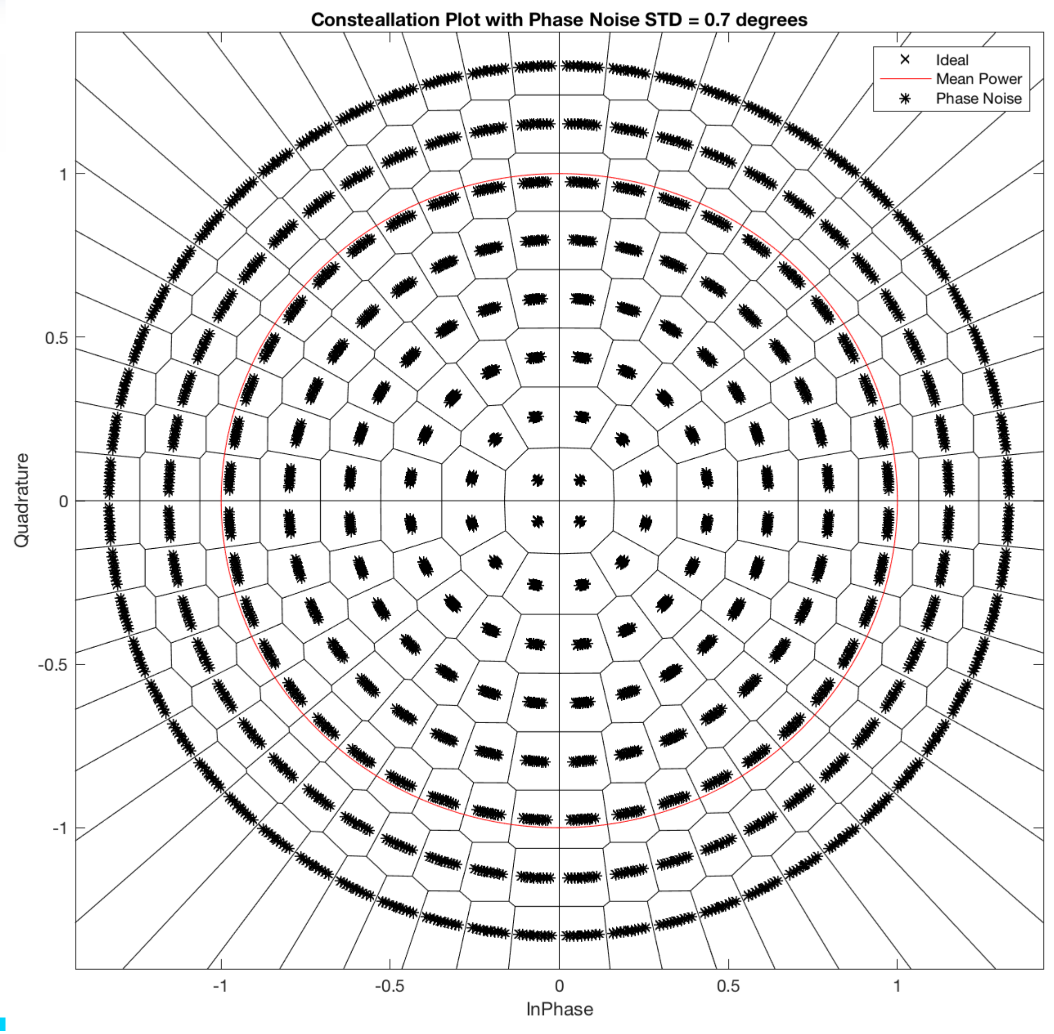


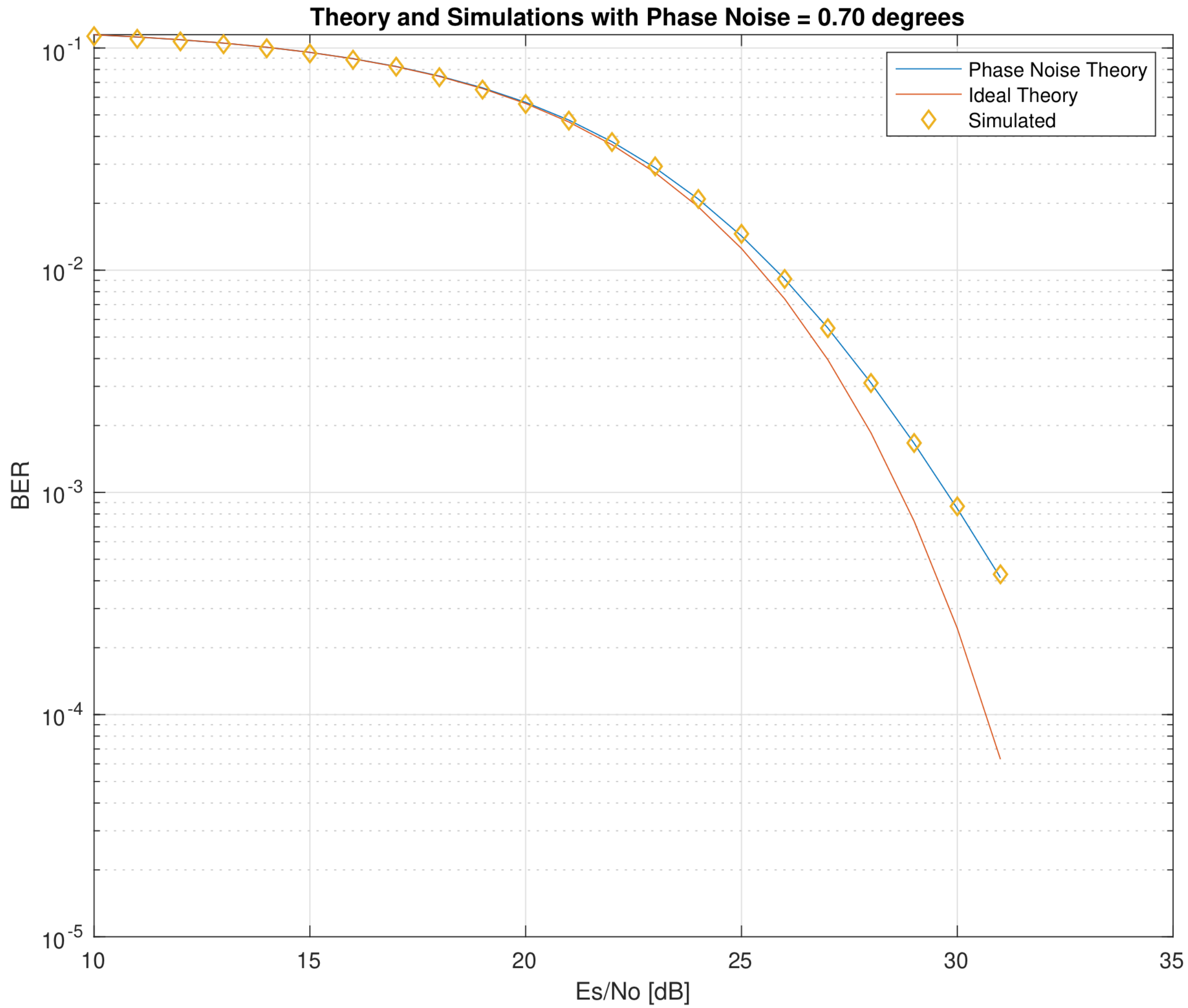


Phase Noise

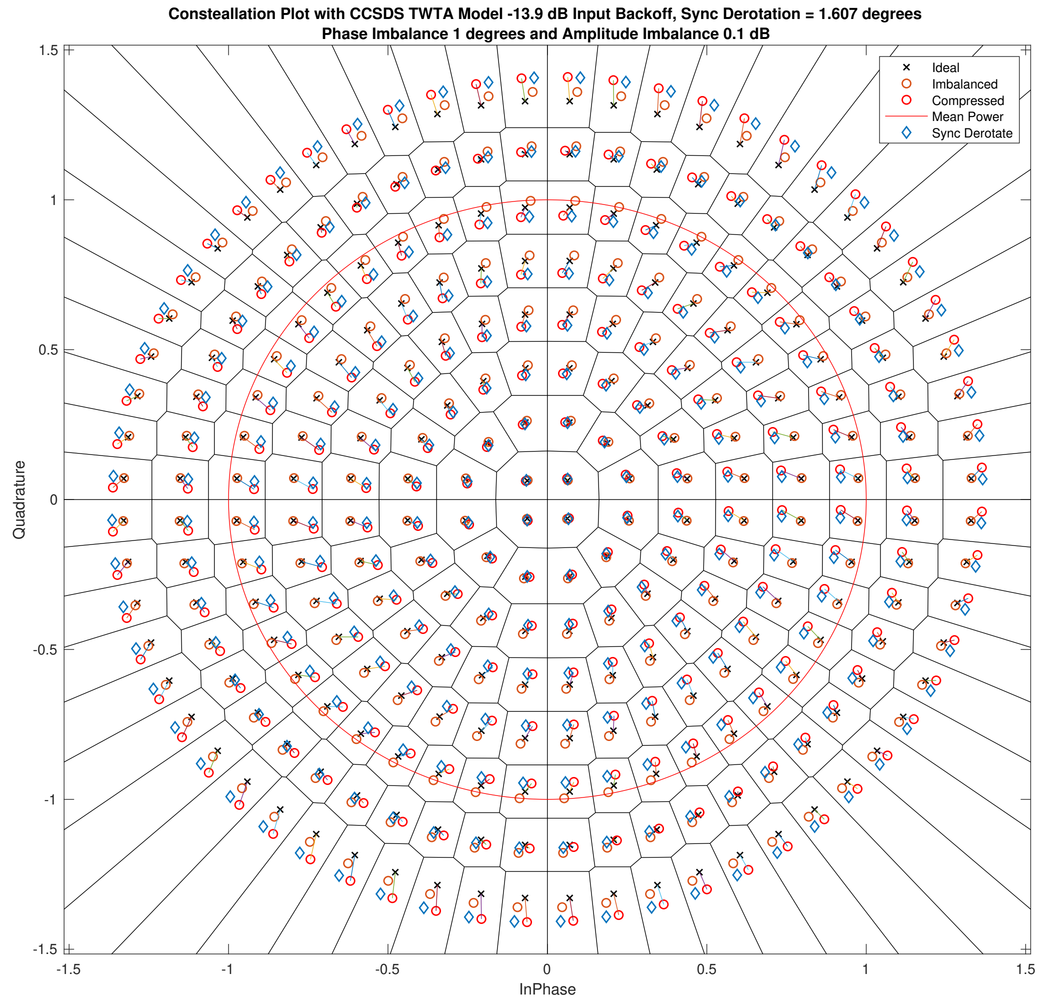
- Following the approach of [Blahut, 2010]:
  - Define the residual phase noise as an approximated Gaussian distribution at the output of phase synchronizer then:
  - Multiply the constellation points by a random rotation: $\exp(-i\omega)$ where ω is a Gaussian RV with STD = σ_ω and a mean of zero.
  - Then probability distribution function: $PDF = \frac{1}{\sqrt{2\pi\sigma_\omega^2}} \exp\left(\frac{-\omega^2}{2\sigma_\omega^2}\right)$
  - Therefore: $$\overline{P}_{e,l} = \int_{-\infty}^{\infty} P_{e,l}(\omega) \frac{1}{\sqrt{2\pi\sigma_\omega^2}} \exp\left(\frac{-\omega^2}{2\sigma_\omega^2}\right) d\omega$$ $$\approx \int_{-3\sigma_\omega}^{3\sigma_\omega} P_{e,l}(\omega) \frac{1}{\sqrt{2\pi\sigma_\omega^2}} \exp\left(\frac{-\omega^2}{2\sigma_\omega^2}\right) d\omega$$ Note: PDF truncated to 99.7%.
  - Discretely: $\overline{P}_{e,l} \approx \sum_{n=1}^{N_\omega} P_{e,l}(\omega(n)) \frac{1}{\sqrt{2\pi\sigma_\omega^2}} \exp\left(\frac{-\omega(n)^2}{2\sigma_\omega^2}\right) \Delta\omega$ where $\Delta\omega = 6\sigma/N_\omega$ and N_ω num. points

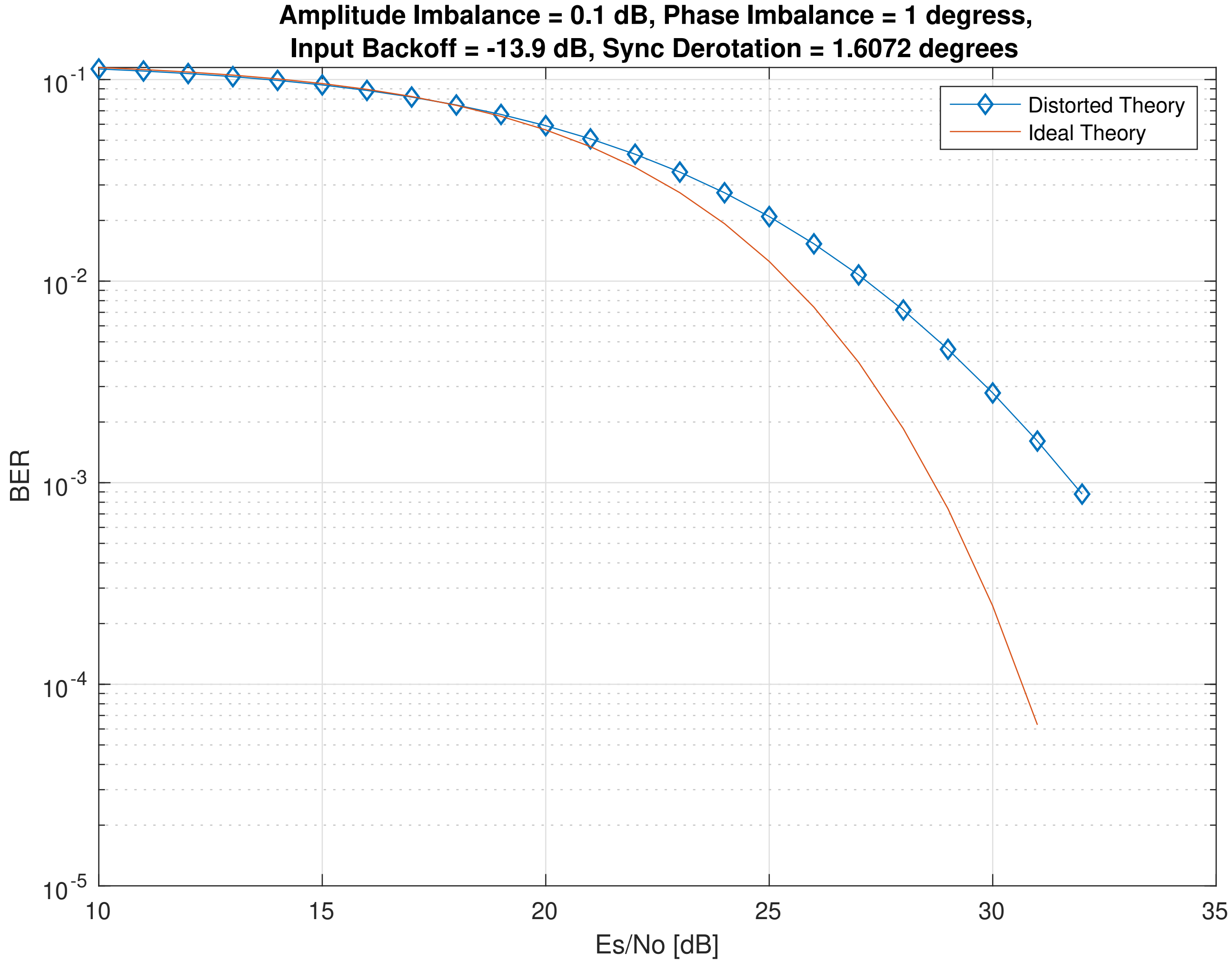
Phase Noise(2)



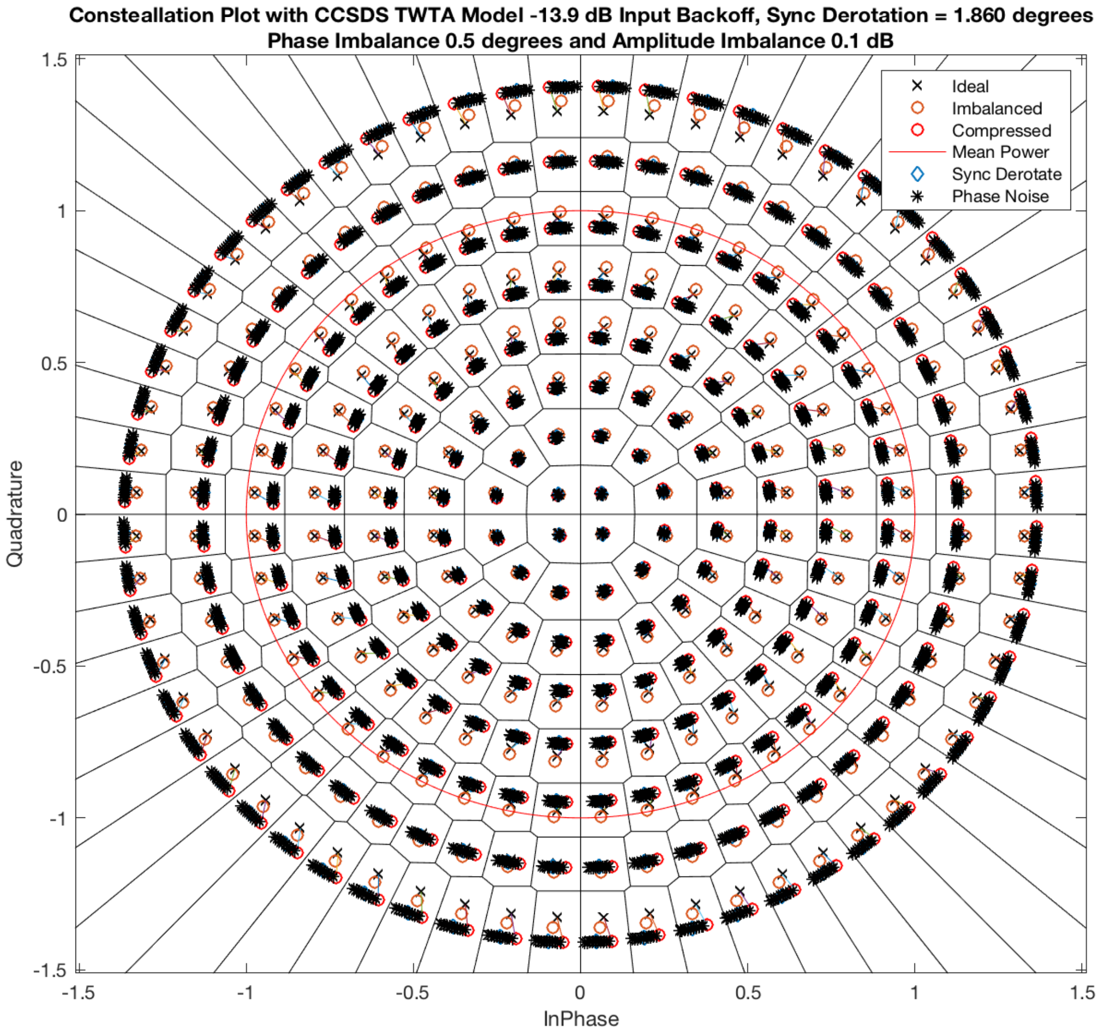


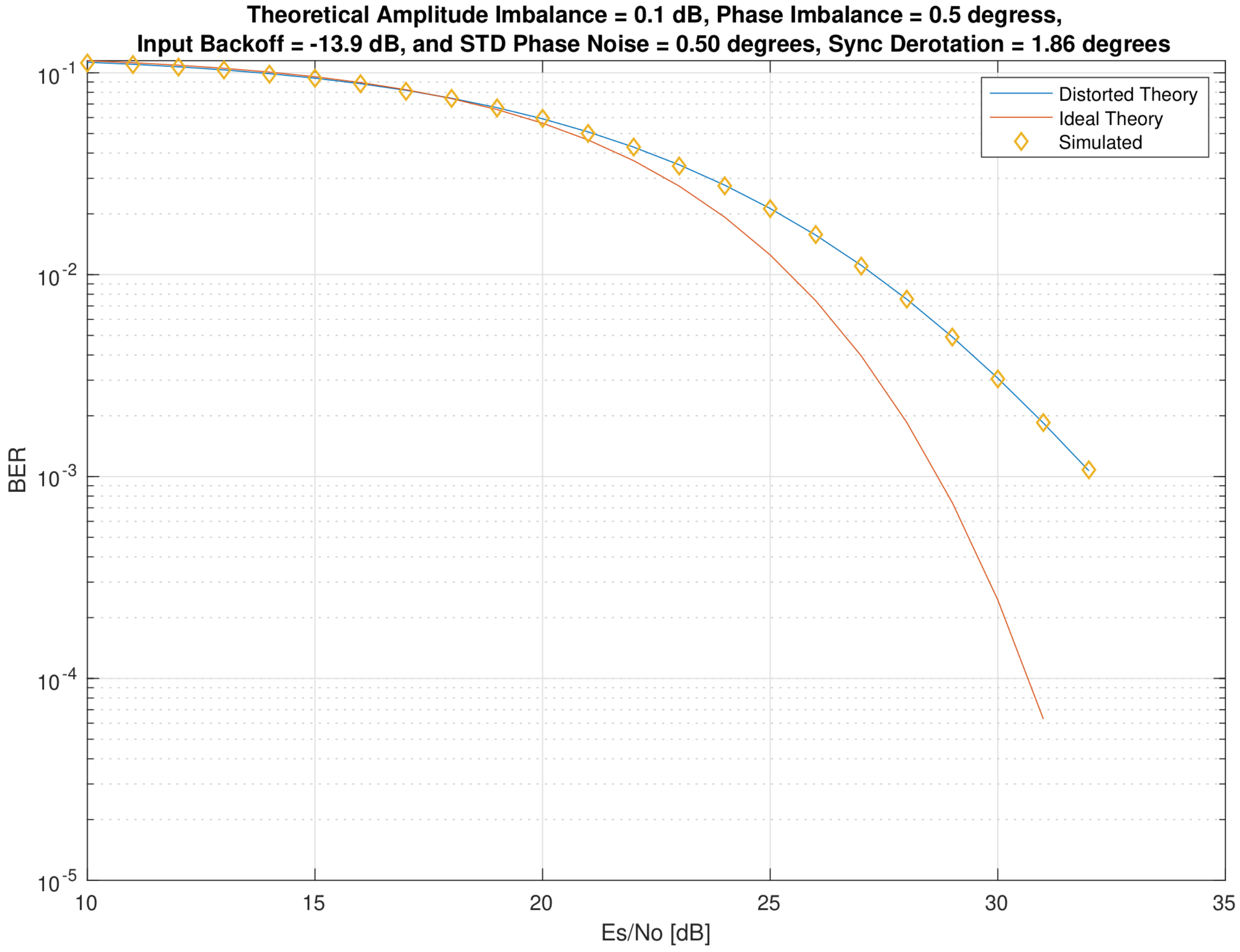
Combined Analysis: Compression and Imbalance



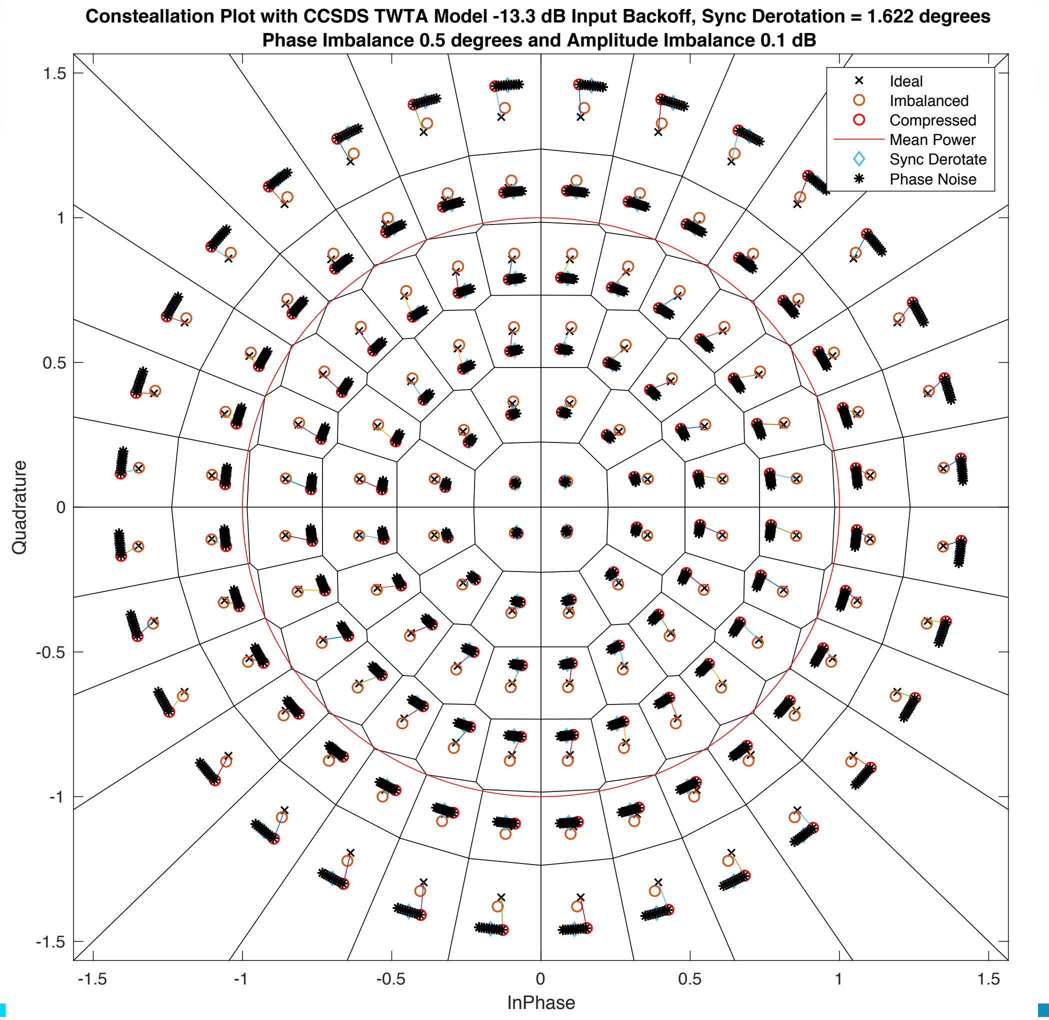


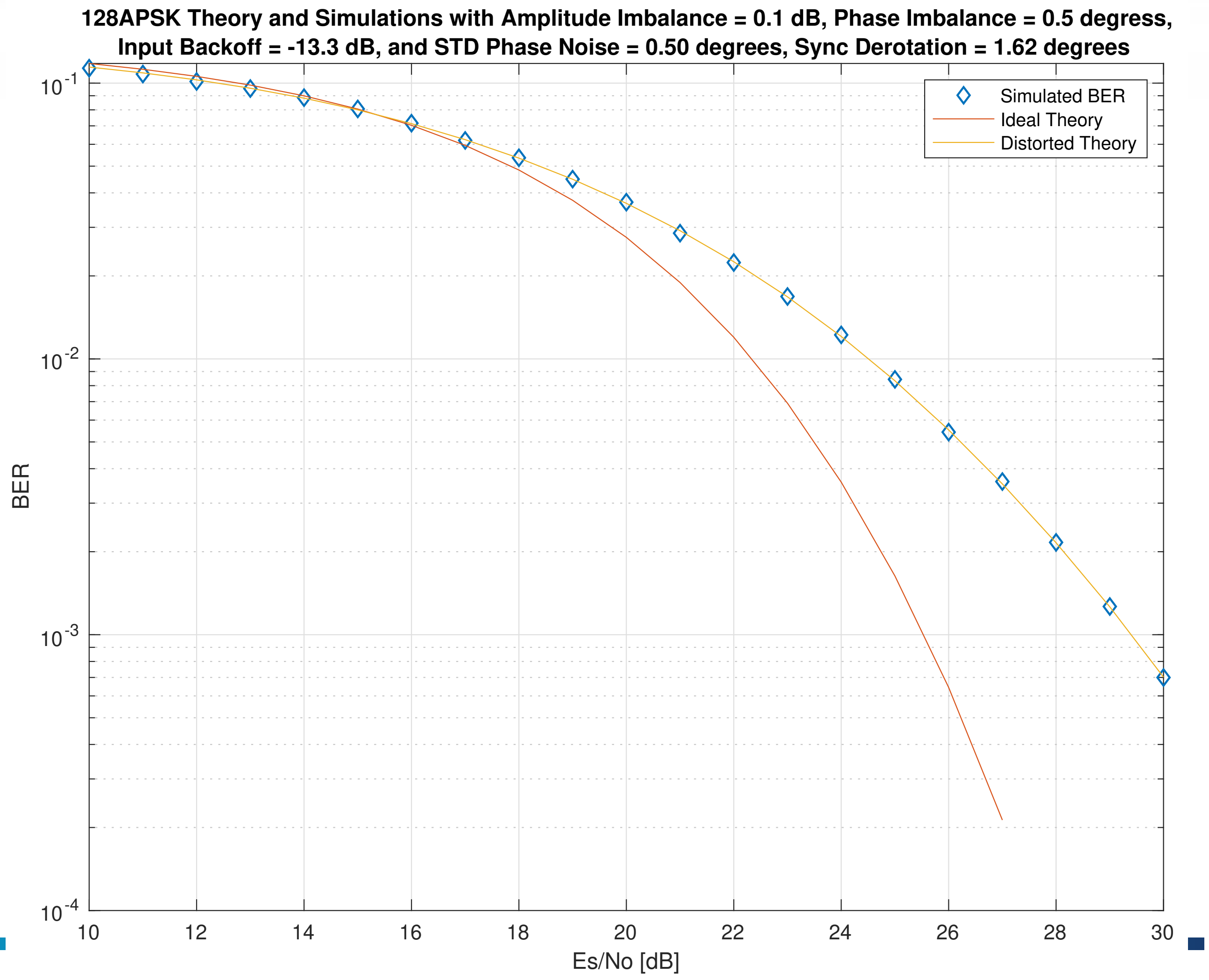
Combined Analysis: Compression, Imbalance and Phase Noise





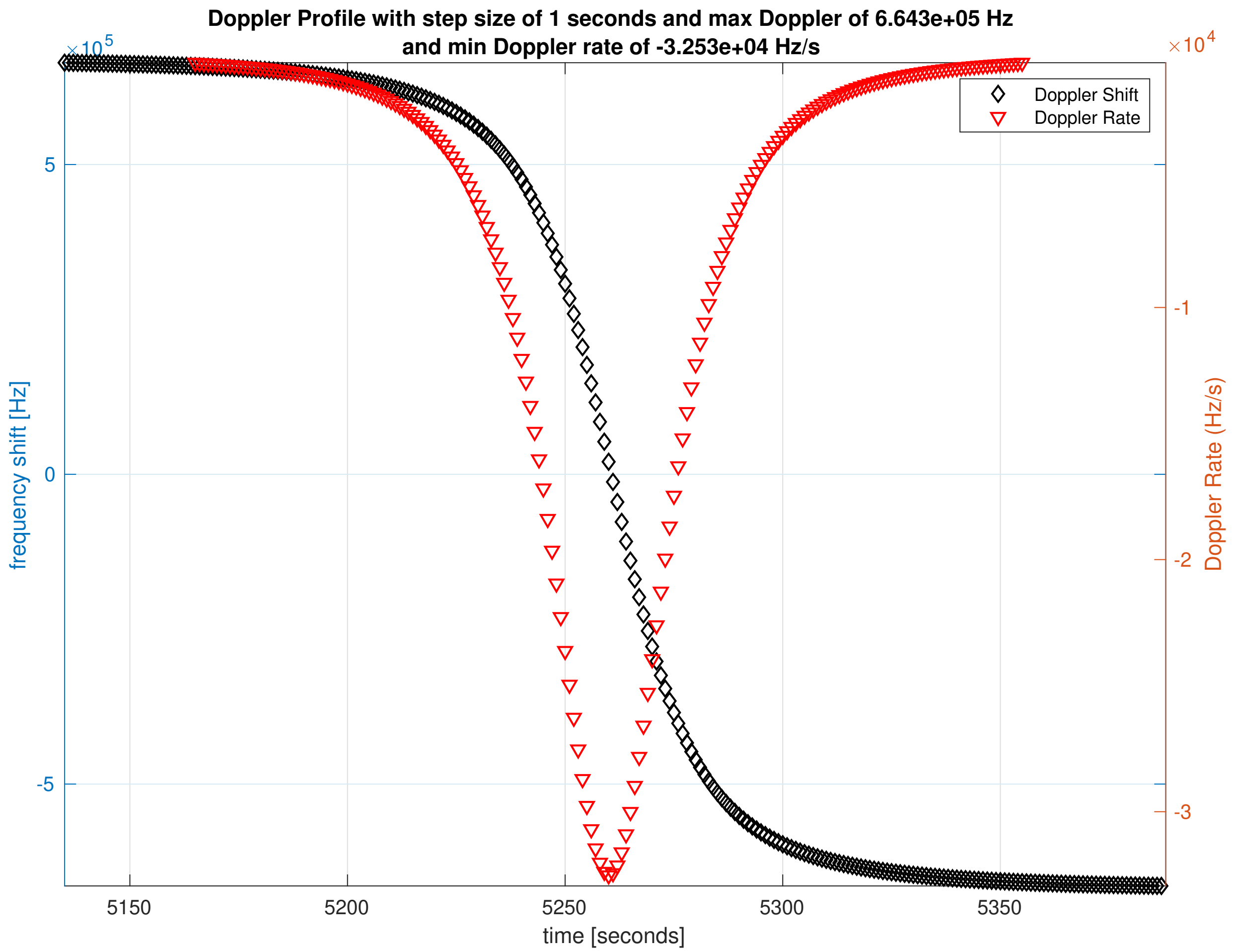
Combined Analysis: Compression, Imbalance and Phase Noise(2)





Doppler Profile

- Defined for Ka band carrier frequency of 26.25 GHz
- LEO orbit at 160 Km direct overhead pass.
- Maximum Doppler freq. shift = 6.643e5 Hz
- Minimum Doppler rate = -3.253e4 Hz/s



Test Configuration

256APSK Testing Parameters	Values
Phase Imbalance	0.5 degrees
Amplitude Imbalance	0.1 dB
CCSDS TWTA Back Off	13.9 dB
Phase Noise Standard Deviation	0.5 degrees

128APSK Testing Parameters	Values
Phase Imbalance	0.5 degrees
Amplitude Imbalance	0.1 dB
CCSDS TWTA Back Off	13.3 dB
Phase Noise Standard Deviation	0.5 degrees

max Doppler frequency shift	± 6.643e5 Hz
min Doppler rate of change	-3.253e4 Hz/s

Table 2: Summary of Test Configuration

Summary

- We have successfully developed an analytical theory that exactly predicts the end-to-end error performance of 256APSK and 128APSK with and without distortions, which to our knowledge has not be published before.
- We have found a set of baseline parameters to evaluate and compare the DVB-S2X and the SCCC-X proposals which we believe should provide a good indicate of the BER performance of each set of the extended modulations and coding combinations.

References

[1] Voronoi, G., "Recherches sur les Paralleloedres Primitives," Journal Reine Angew Mathematique, vol. 134, pp. 198-287, 1908.

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[4] Chrisikos, G., "Analysis of 16-QAM Over a Nonlinear Channel," Ninth IEEE International Symposium on Personal, Indoor and Mobile Radio Communications, Boston, MA, USA, 1998, pp. 1325-1329 vol.3.

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References(2)

[6] Gharaibeh, K. M., *Nonlinear Distortion in Wireless Systems*, IEEE Press, Wiley and Sons, West Sussex, UK, 2012.

[7] J. Kim and K. Konstantinou, "Digital Predistortion of Wideband signals Based on Power Amplifier Model with Memory", *Electronic Letters*, Vol. 37, No. 23, Nov. 2001, pp. 1417-1418.

[8] L. Ding, G. T. Zhou, D. R. Morgan, Z. Ma, J. S. Kenney, J. Kim, and C. R. Giardina, "A Robust Digital Baseband Predistorter Constructed Using Memory Polynomials," *IEEE Transactions on Communications*, Vol. 52, No. 1, Jan. 2004, pp.159-165.

Acronyms

CCSDS: Consultative Committee on Space Data Standards
CNES: Centre National d'Etudes Spatiales
ESA: European Space Agency
DVB-S2: Digital Video Broadcast Second Generation
DVB-S2X: Digital Video Broadcast Second Generation Extension
SCCC: Serially Concatenated Convolutional Codes
SCCC-X: Serially Concatenated Convolutional Codes Extension
SLS-RFM: Space Link Services-Radio Frequency and Modulation
SLS-CS: Space Link Services-Coding and Synchronization
BER: Bit Error Rate
STD: Standard Deviation
RV: Random Variable
PDF: Probability Distribution Function
LEO: Low Earth Orbit
NASA: National Aeronautic and Space Administration
GSFC: Goddard Space Flight Center
APSK: Amplitude Phase Shift Keying
GHz: Giga Hertz
Hz: Hertz
Hz/s: Hertz per second
dB: decibels

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