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EVM and SER Performance of OFDM Signals with Different IFFT Sizes Under Nonlinear Distortion

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Outline

- Introduction
  - Orthogonal-Frequency Division Multiplexing (OFDM) signals in presence of noise and distortion
  - Error Vector Magnitude (EVM) and Symbol Error Rate (SER)
  - Peak-to-Average Power Ratio (PAPR) of OFDM
- Simulated EVM performance in presence of nonlinearity
  - Polynomial model results
  - Rapp model results
- SER performance (for polynomial and Rapp models)
  - QPSK results
  - 64-QAM results
- Conclusions and Future work

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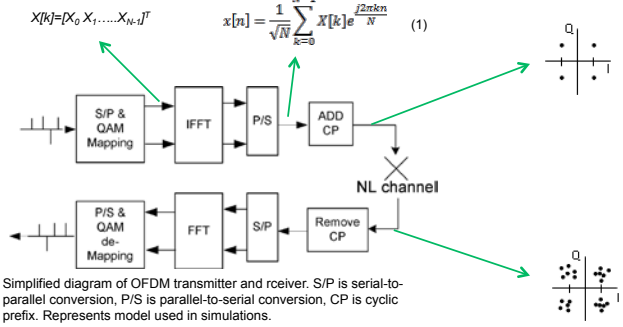
OFDM signal distortion

$X[k]=[X_0\ X_1 \ldots X_{N-1}]^T$

$$x[n] = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X[k] e^{\frac{j2\pi kn}{N}} \quad (1)$$



Simplified diagram of OFDM transmitter and rceiver. S/P is serial-to-parallel conversion, P/S is parallel-to-serial conversion, CP is cyclic prefix. Represents model used in simulations.

- Received constellation is impaired by noise and distortion arising from nonlinearities in the channel.
- For direct intensity-modulation and direct-detection (IM-DD) RoF links at microwave frequencies, and short-to-medium reach applications, the main source of nonlinearity is the laser diode.

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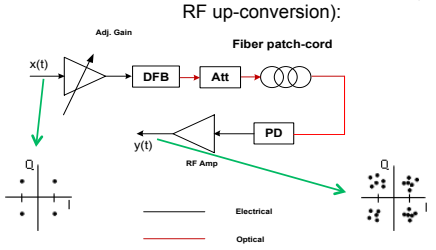
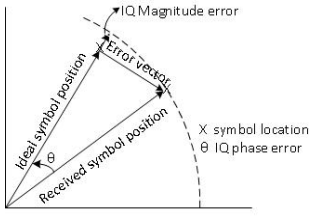
EVM and SER

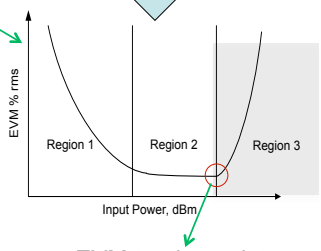
RoF link: example of nonlinear channel (following DAC and RF up-conversion):



DFB: Distributed Feedback laser; PD: Photodiode; Att optical attenuator.

Error vector magnitude analysis:





EVM turning point

- Usually, following (or prior to) transmission through RoF link, the signals will be transmitted through a wireless channel.
- An input RF power back-off point based on the EVM turning point should be used.

- EVM represents average signal modulation quality of the link.
- SER on the other hand is a counting process - under distortion conditions may present performance trends that differ from those expected from the EVM behavior under noise regime

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PAPR of OFDM

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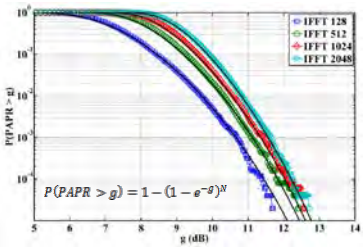
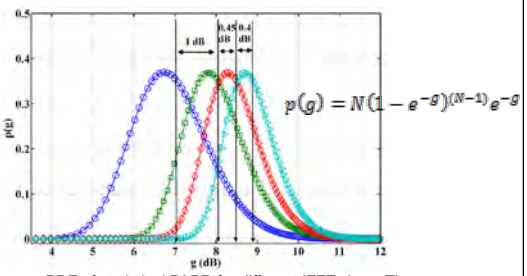
- In-phase and Quadrature components formed by summation of a large number of discrete-time sinusoids (OFDM subcarriers).

$$x[n] = \frac{1}{\sqrt{N}}\left[\sum_{k=0}^{N-1}\left[|X[k]|\cos\left(\frac{2\pi kn}{N}\right) + arg(X[k])\right] + j\sum_{k=0}^{N-1}\left[|X[k]|\sin\left(\frac{2\pi kn}{N}\right) + arg(X[k])\right]\right]$$

- Composite envelope peak power much greater than average power: $PAPR = {max\{x[n]\}^2}/{E\{x[n]^2\}}$
- Assuming QAM symbols are drawn from a uniformly distributed process and are independent and identically distributed, more practical statistical description is obtained for the PAPR using the Central Limit Theorem:



CCDF of PAPR: solid traces are analytical results, points are simulation results from Matlab.



PDF of statistical PAPR for different IFFT sizes. The annotations correspond to differences between the medians for different IFFT sizes.

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EVM performance (poly)

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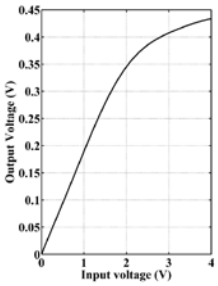
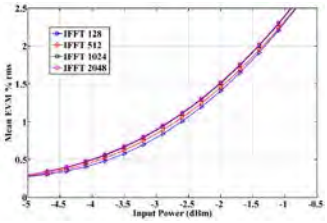
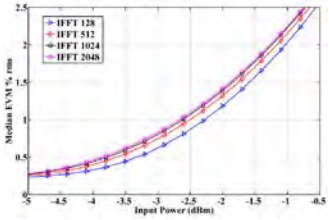


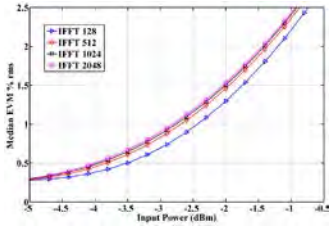
9th order polynomial extracted from the amplitude-modulation-to-amplitude-modulation (AM/AM) response of a Teradian laser diode.



Mean EVM results versus input power for polynomial and QQPSK modulation.



Median EVM versus input power results for the polynomial with QPSK modulation.



Median EVM versus input power results for the polynomial with 64-QAM modulation.

- Differences between the IFFT sizes are not pronounced.
- Note small EVM floor due to numerical errors – may mask turning points
- Clear difference in curves when referring to the median instead of the mean EVM. - in agreement with the observed trends in [1]

[1] P. Assimakopoulos, A. Nkansah, N. J. Gomes and D. Wake, "Statistical distribution of EVM measurements for direct-modulation radio over fiber links transporting OFDM signals," *IEEE Trans. Microw. Theory Tech.*, Vol. 61, No. 4, pp. 1709-1717, April 2013.

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EVM performance (Rapp)

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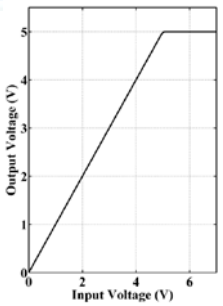
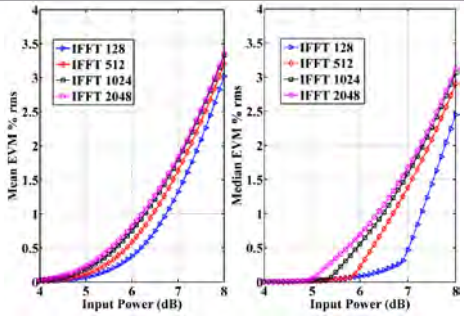


Rapp band-pass model. Amplitude characteristic



Mean (left) and median (right) EVM results versus input power for the Rapp model and QPSK modulation.

- Rapp band-pass nonlinear model with sharp transition into saturation
- For mean EVM, differences between turning points of the EVM for the different traces are very small.
- For median EVM, differences between the turning points are more pronounced.

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Discussion

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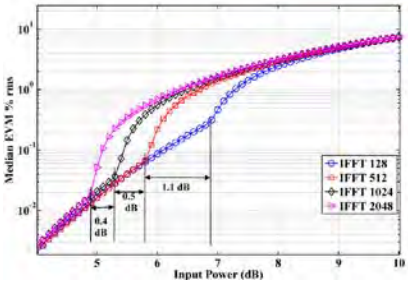
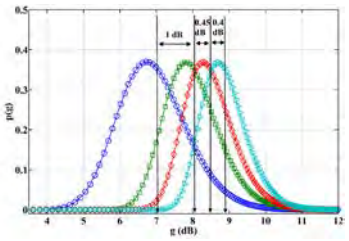


Median EVM versus input power results for the Rapp model with QPSK modulation. The y-axis is in log-scale.

Reason behind observed behaviour:

- Under AWGN conditions, EVM_k follows a Rayleigh distribution. However, under distortion conditions the distribution becomes a positively skewed Rayleigh distribution, with the skew being larger for smaller IFFT sizes.
- Differences in input powers of turning points more-or-less agree with those predicted by the differences in the medians of the PAPR traces.

- Result shows direct and specific quantifiable connection between EVM performance and PAPR for different IFFT sizes
- Input powers at which the turning points occur are approximately equal to the difference between the saturation level (5 V or 14 dB input power referred to 1 ohm) of the nonlinearity and the median of the PAPR



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SER performance (QPSK)

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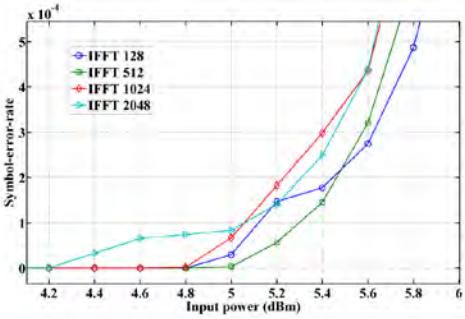
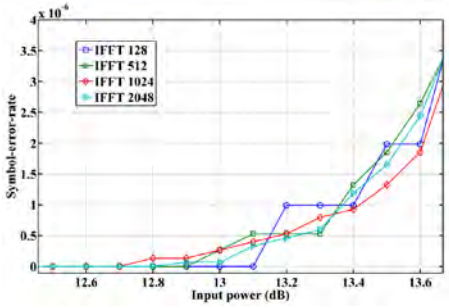


SER results versus input power for the transmission of 10000 OFDM symbols with QPSK modulation for the polynomial model.



SER results versus input power for the transmission of 10000 OFDM symbols with QPSK modulation for the Rapp model.

- Larger IFFT sizes start to produce errors at lower input powers.
- However, clear trend dependent on IFFT sizes is not observed.

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SER performance (64-QAM)

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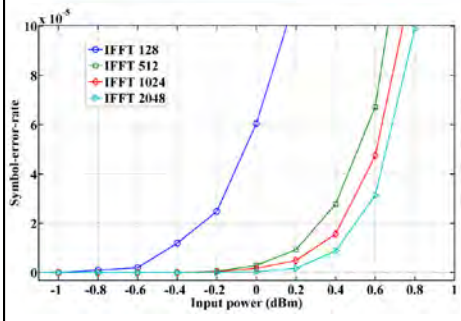
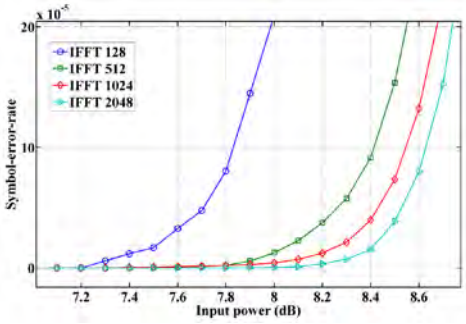


SER results versus input power for the transmission of 10000 OFDM symbols with 64-QAM modulation for the polynomial model.



SER results versus input power for the transmission of 10000 OFDM symbols with 64-QAM modulation for the Rapp model.

- Clear trend is observed, where the smaller IFFT sizes tend to produce errors at lower input powers.
- Behavior may seem opposed to that expected from the EVM performance.

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Discussion

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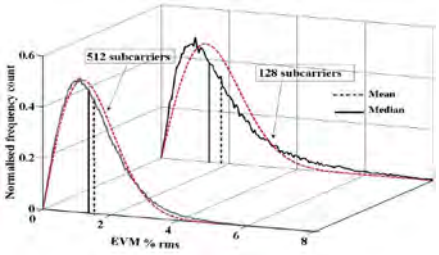
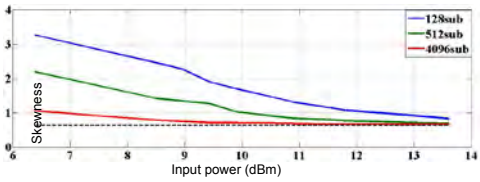
Reason behind observed trends:

- Under distortion conditions, the distribution of EVM_k is positively skewed, with higher skew for smaller IFFT sizes.
- Outliers in this distribution result in symbol errors at lower input powers.
- The skew in the distribution starts to increase with the onset of distortion. But as input power is further increased, distortion effects become more white-noise-like and differences in skew between different IFFT sizes reduces.
- For QPSK symbol errors occur at higher input power (compared to 64-QAM), by that point skew differences have diminished.



Distributions of raw EVM for 128 and 512 IFFT sizes. The dashed traces are Rayleigh fits [1].



Skew of the raw EVM distributions for 128, 512 and 4096 IFFT sizes. The dashed trace is the Rayleigh distribution skew [1].

[1] P. Assimakopoulos, A. Nkansah, N. J. Gomes and D. Wake, "Statistical distribution of EVM measurements for direct-modulation radio over fiber links transporting OFDM signals," *IEEE Trans. Microw. Theory Tech.*, Vol. 61, No. 4, pp. 1709-1717, April 2013.

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Conclusions

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- Investigation carried out into relationship between PAPR and two performance metrics, the EVM and SER, under nonlinear distortion conditions.
- Analysis applied to a RoF link:
  - Polynomial model fit to a laser diode AM/AM response.
  - Concentrated on the turning point of the EVM, on which the back-off operation point in RoF links is often based, to ensure minimum performance degradation of the transported signals.
- But, main conclusions are more generally applicable:
- Direct relation between the PAPR and EVM performance exists.
- Different IFFT sizes give different EVM performances as expected from their statistical PAPR (verification of measured results).
- SER results show that for small modulation levels, larger IFFT sizes will tend to produce errors at lower input powers (compared to smaller IFFT sizes).
- However, for large modulation levels a clear trend is observed: Smaller IFFT sizes produce errors at lower input powers (compared to larger IFFT sizes).

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Future work

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- Investigate SER for AWGN channels and relate input power at which symbol error onset occurs with EVM turning point.
- Investigate SER of nonlinear case and relate input power at which symbol error onset occurs with EVM turning point.

- Difference between nonlinear and AWGN cases can provide amount of input power back-off required for the different IFFT sizes.

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Thank you

Any questions?

Acknowledgement:

Dr Anthony Nkansah for the initial OFDM modelling