Crest Factor Reduction for Down-link LTE by Transmitting Phase Shifted Resource Blocks

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Goal

- Crest factor reduce (CFR) the LTE down-link waveform.
  - OFDM.
  - High PAPR (peak to average power ratio).
- Modify Partial Transmit Sequence (PTS) approach to CFR
  - Exploit the structure of the LTE down-link waveform.
  - Improve computational efficiency.

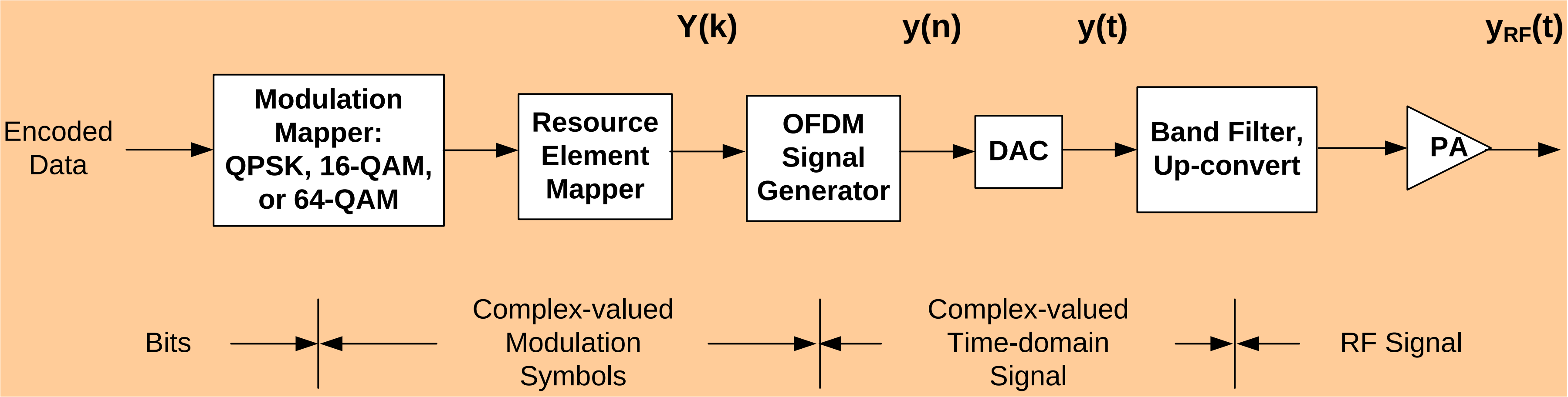
Outline

- Brief summary of CFR approaches.
- Review LTE down-link waveform.
  - Modulation
  - Demodulation
- Proposed method (exploiting the down-link LTE structure).
  - Apply phase shifts to resource blocks during modulation.
  - Equalize resource blocks independently during demodulation.
- Proposed CFR algorithm.
  - Apply small phase shifts to many resource blocks instead of π radians shifts to a few.
  - Descent-based optimization instead of an exhaustive search.

Summary of CFR Approaches

- Clip and filter
  - Find peaks above a threshold and create a clipped error waveform.
  - Bandlimit clipped error and subtract it from original waveform.
  - Increases EVM.
- Tone reservation
  - Transmit sequences on unused sub-carriers to reduce peaks.
  - Increases Tx power, reduces throughput.
- Constellation extension
  - Map opposing constellation points to one symbol: $c_{IQ} = -c_{IQ}$.
  - Reduces throughput (QPSK ½, 16QAM ¾, 64QAM 5/6).
- Partial transmit sequence (PTS), selective mapping (SLM)
  - Phase shift blocks of sub-carriers to reduce peaks.
  - Phase shift vector must be transmitted to the receiver.

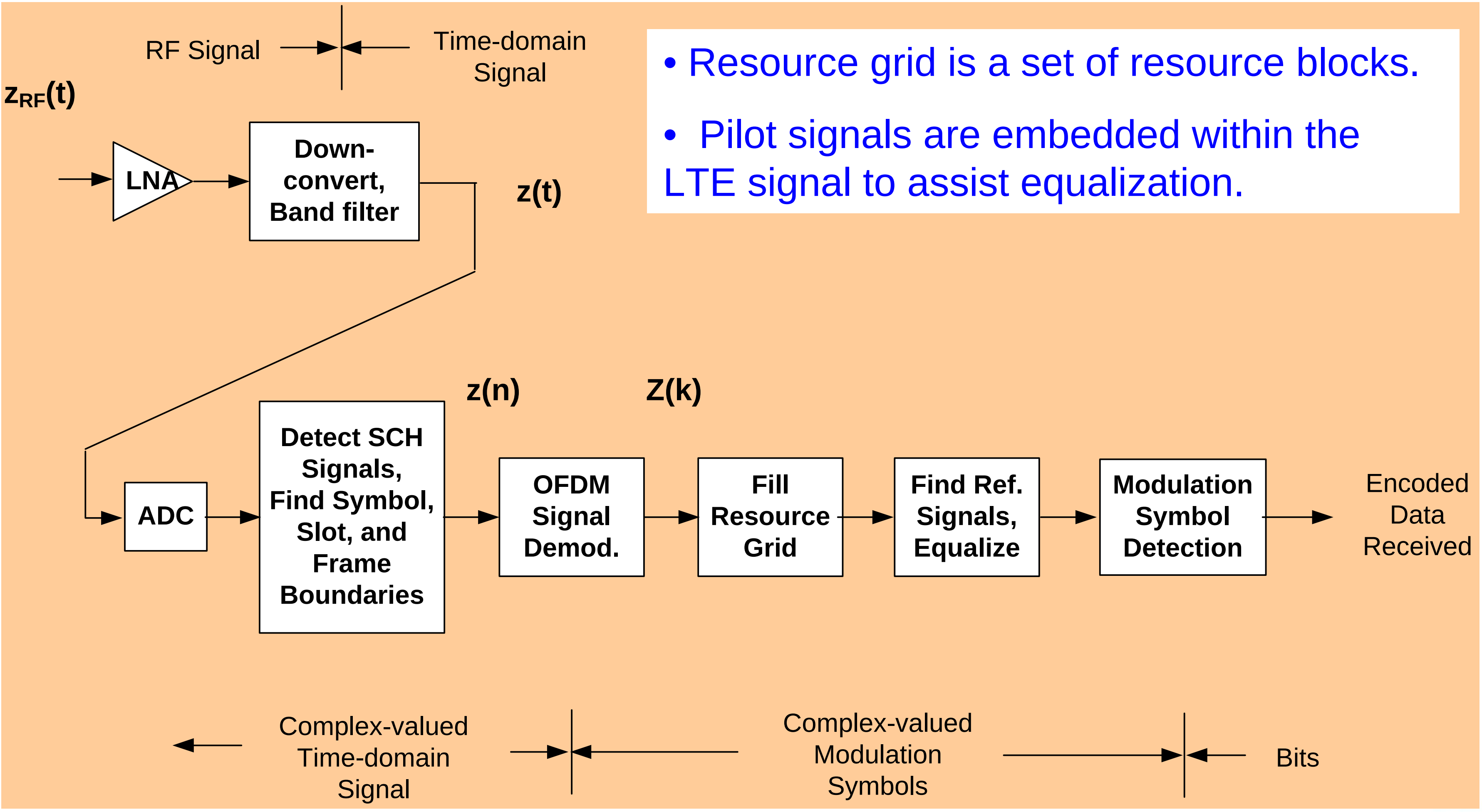
LTE Down-link Waveform



- Resource element
  - time-frequency point holding modulated data.
  - QPSK, 16QAM, 64QAM modulation.
- Resource block
  - Group of resource elements contiguous in time and frequency.
  - Minimum allocation unit for data transmission.

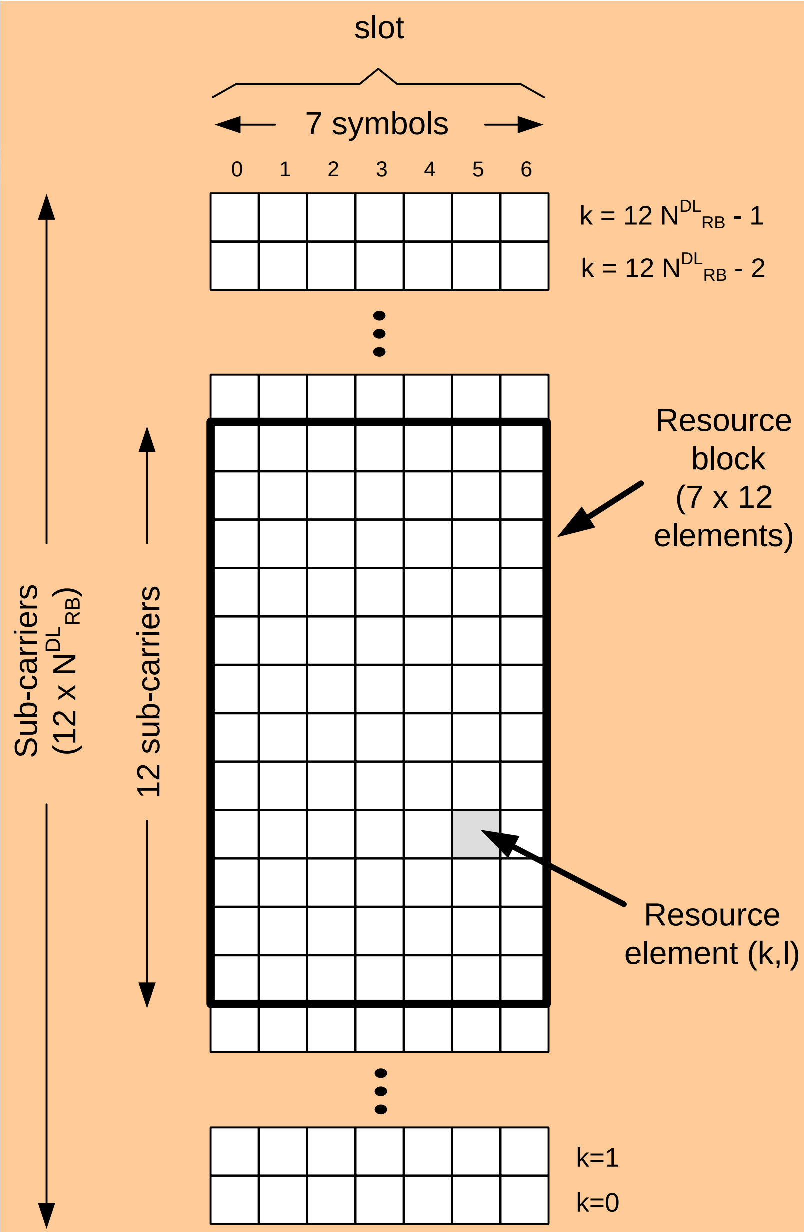
LTE Down-link Receiver

- Resource grid is a set of resource blocks.
- Pilot signals are embedded within the LTE signal to assist equalization.



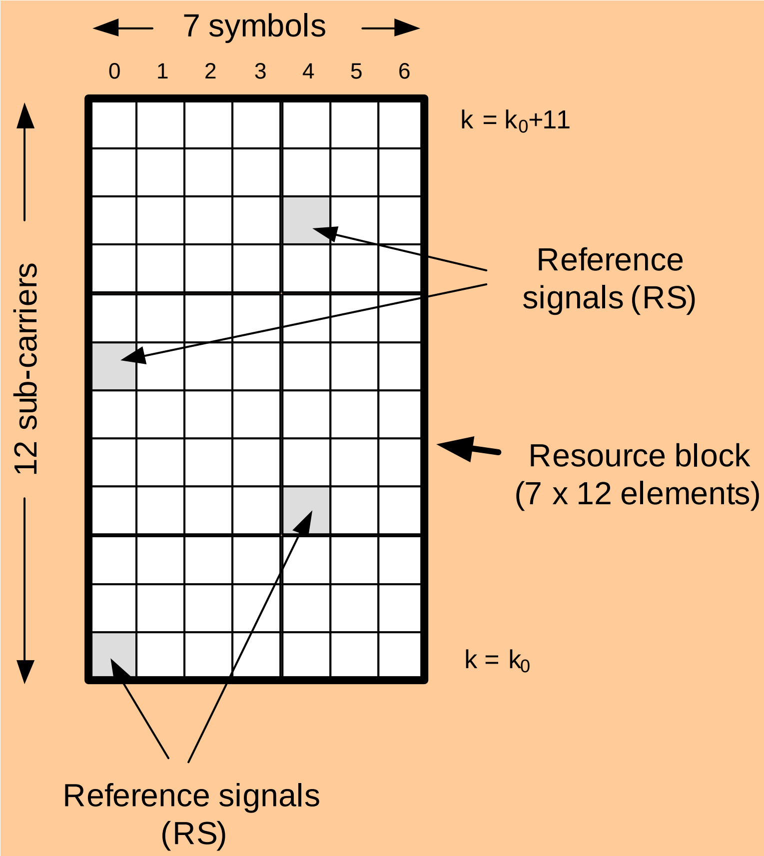
Resource Grids, Blocks, and Elements

- Resource Grid
  - Several resource blocks (RB's).
  - Number of RB's adjusted to cover available BW.
- Resource Block (RB)
  - 7 by 12 elements.
  - Transmissions are allocated in discrete RB's.
- Resource element
  - one symbol width in time
  - one 15 kHz sub-carrier in frequency.

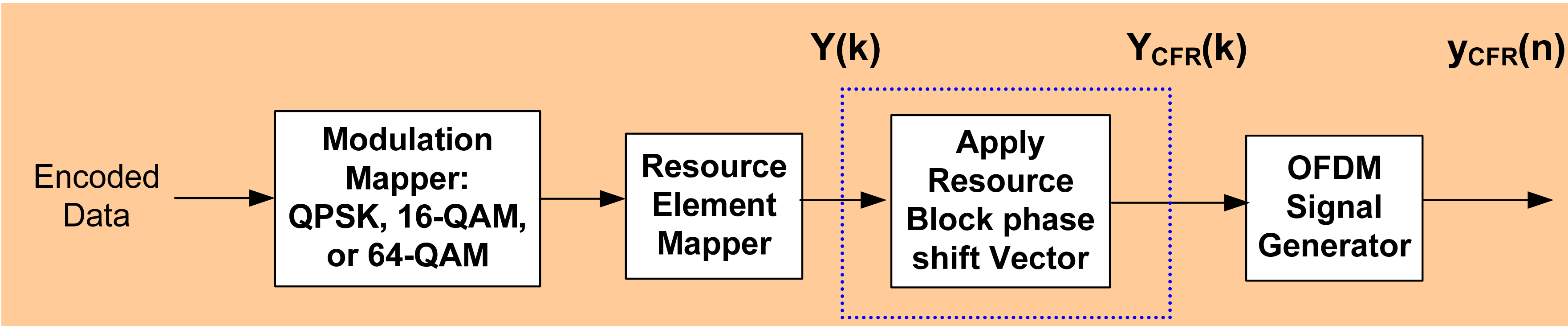


LTE Reference Signal (RS)

- Reference signals
  - Pilot signals.
  - Occupy four elements per resource block for the single antenna port case.
- Used by the receiver
  - Equalize channel propagation.
- Proposed approach
  - Use the 4 available reference signals to equalize each resource block independently.
  - A phase shift applied to a RB is removed during demodulation.



LTE Down-link CFR



- Phase shift vector
  - Phase shift resource blocks to reduce peaks..

Partial Transmit Sequence CFR for OFDM

- Original OFDM signal

$$y(t) = \Sigma\, Y_k \exp[\, j\, k\, \Delta\omega\, t\,]$$

- CFR'ed signal

$$y_{CFR}(t) = \Sigma\, Y_k \exp[\, j\, (k\, \Delta\omega\, t + \theta_k)\,]$$

- Select phase shift vector θ_k to reduce peaks.
  - Phase shift groups of subcarriers.
  - Resource blocks for LTE case.

Baseline Approach for PTS

$$y_{CFR}(t) = \Sigma\, Y_k \exp[\, j\, (k\, \Delta\omega\, t + \theta_k)\,]$$

- Restrict allowable phase shifts to reduce search space.
  - $\theta_k = [0,\pi]$ radians.
- Neighborhood gradient search (NGS). [Han & Lee]
  – Phase shift one resource block by π radians.
  – Test if max{ $|y_{CFR}(t)|$ } > max{ $|y(t)|$ }
  – Apply phase shift to next RB and retest (for all remaining RB's).
  – Retain best $y_{CFR}(t)$.
  – Make $y(t) = y_{CFR}(t)$, and repeat to introduce additional phase shifts.
- Sub-optimal search.
  – Number of FFT / IFFT = (num of RB's) x (num of phase shifts).

Small Phase Angle CFR for OFDM

$$y_{CFR}(t) = \Sigma\, Y_k \exp[\, j\, (k\, \Delta\omega\, t + \theta_k)\,]$$

- Clipped peaks signal

$$y_{peaks}(t) = y(t) - y_{CFR}(t)$$

- For small angles $|\theta_k|$

$$\Sigma\, Y_k\, \theta_k \exp[\, j\, k\, \Delta\omega\, t\,] \approx j\, y_{peaks}(t)$$

  - FFT of desired j $y_{peaks}(t)$ provides phase shift vector θ_k.
  - Not practical to phase shift each resource element separately.
  - Modify approach by phase shifting resource blocks.

Proposed Approach (one iteration)

- Compute peak signal (exceeds threshold λ)

$$y_{peaks}(n) = \begin{cases} y(n) - \lambda \cdot \dfrac{y(n)}{|y(n)|} & for \quad |y(n)| > \lambda \\ 0 & otherwise \end{cases}$$

- Cross-correlate Y = FFT{y} and Y_{peaks} = FFT{y_{peaks}}
  - for each resource block b

$$C_{RB}(b) = \Sigma_k \Sigma_l \; Y(k,l) \; Y_{peaks}(k,l)^*$$

- Compute phase shift

$$\theta(b) = \begin{cases} |\Delta\theta| \cdot \mathrm{sgn}(\mathrm{Im}\{C_{RB}(b)\}) & for \quad \mathrm{Re}\{C_{RB}(b)\} > 0 \\ 0 & otherwise \end{cases}$$

Complexity Comparison

- Number of FFT / IFFT calculation made (N_{FFT}).
- Proposed approach (small phase shifts)

$$N_{FFT} = 2\,N_{iter} + 1$$

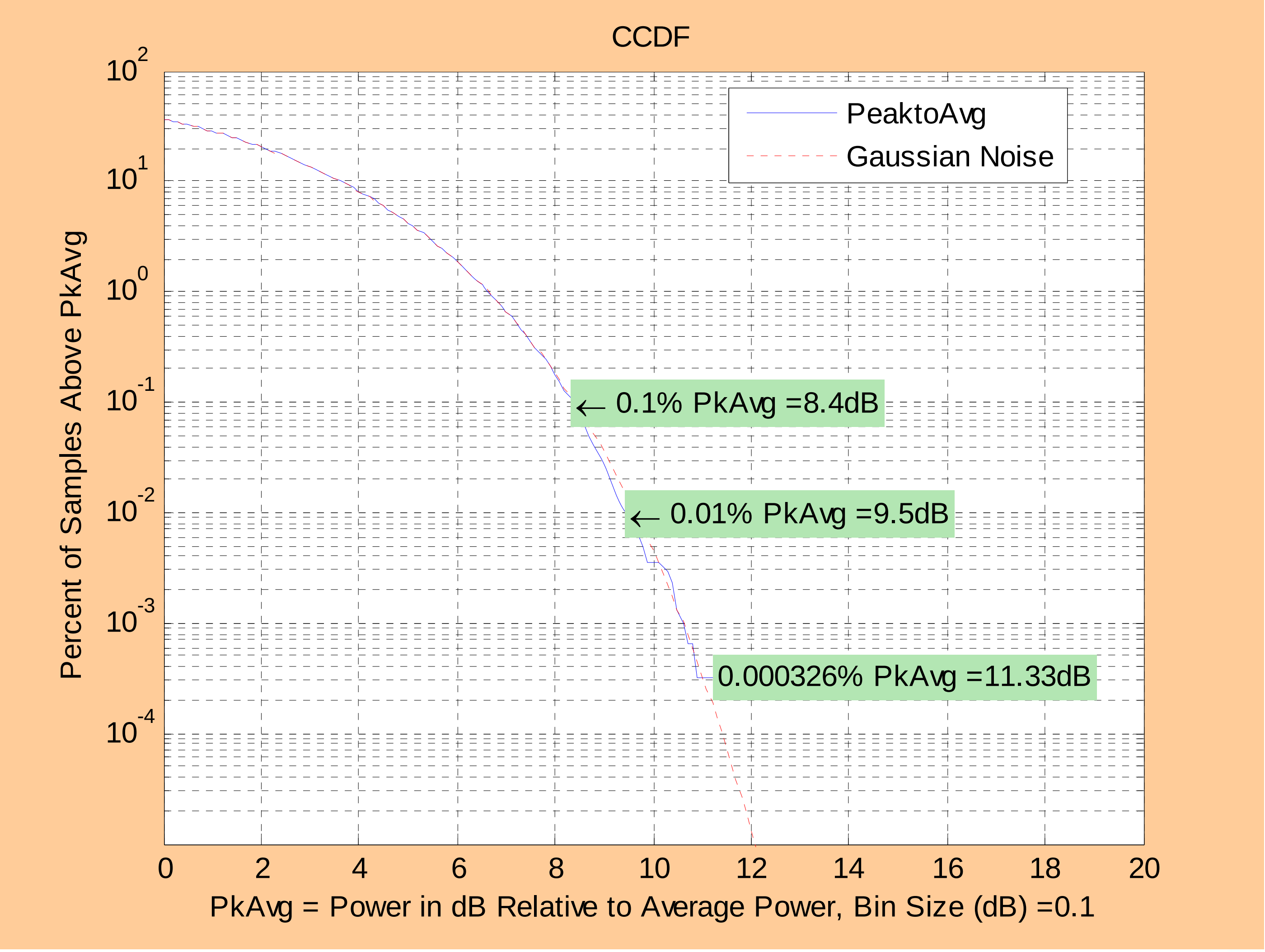
  - Number of iterations N_{iter} = 3, typically. (N_{FFT} = 7).
- Baseline approach (NGS)

$$N_{FFT} = N_{RB}\,N_{iter}$$

  - Number of resource blocks N_{RB} = 50 for 10 MHz BW.
  - N_{iter} is also the number of π phase shifts applied (4.2 on average).
  - N_{FFT} = 210.
- Proposed approach is better.

Results: LTE waveform, No CFR

- CCDF of LTE is similar to that of Gaussian noise.
- PAPR = 11.3 dB.



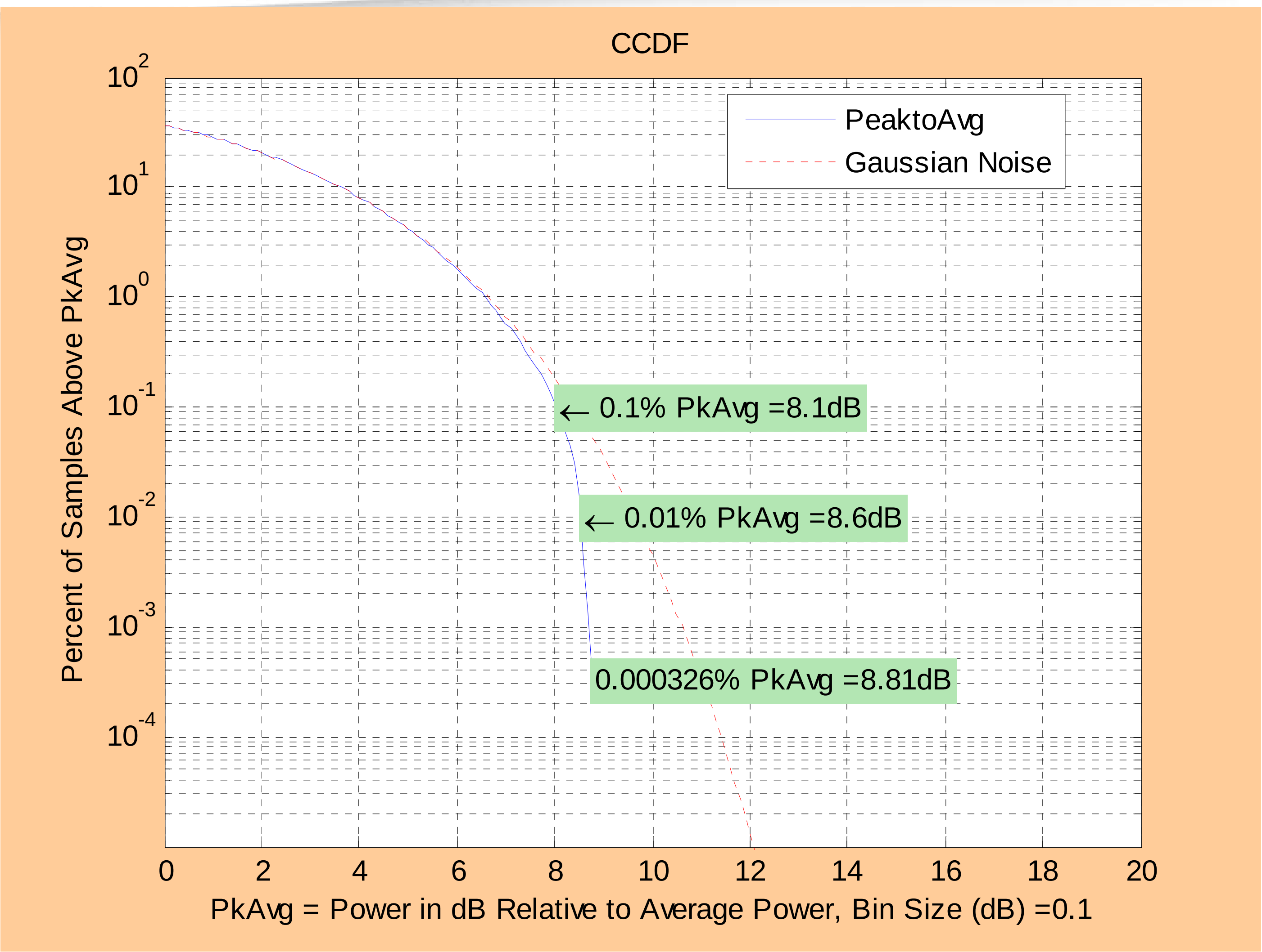
Results: Baseline CFR (NGS)

- NGS CFR reduces the PAPR by 2.5 dB.
- PAPR = 8.8 dB.

  EVM = 0.

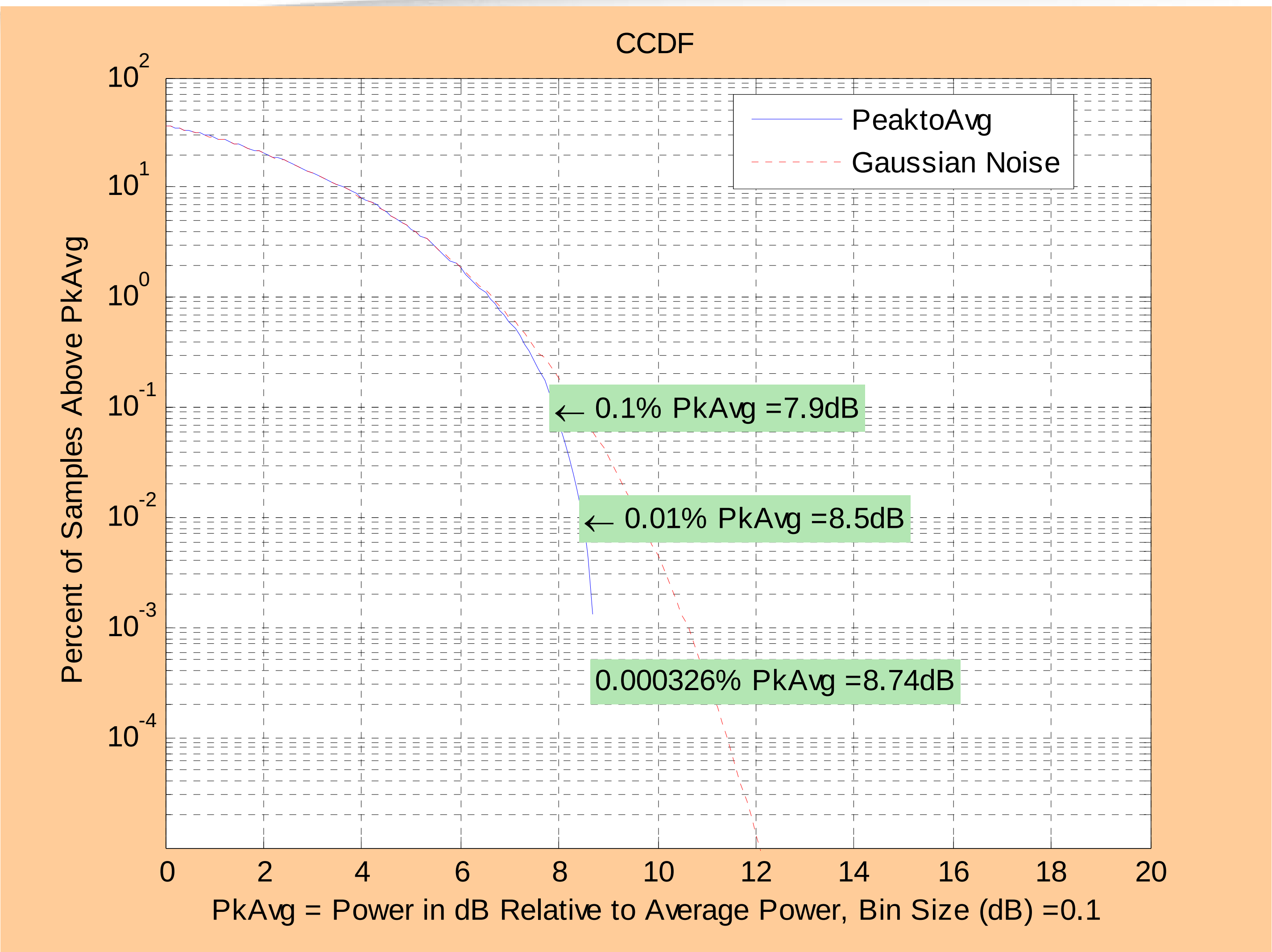
- Compare clipping to 8.8 dB

  3.5% EVM



Results: Proposed Approach (small |θ|)

- Proposed CFR reduces PAPR by 2.6 dB.
- PAPR = 8.7 dB.
- Slightly better than baseline.



Conclusion

- CFR method for LTE.
  - Modification of the partial transmit sequence (PTS) approach.
  - Apply phase shifts to resource blocks during modulation.
  - Equalize resource blocks independently during demodulation.
- Computationally efficient search algorithm.
  - Apply small phase shifts to many resource blocks instead of π radians shifts to a few.
  - Descent-based optimization instead of an exhaustive search.