Constant-Envelope Variations of OFDM and OFDM-CDMA

J. W. Nieto

Harris Corporation

RF Communications Division

Presentation Overview

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- OFDM and OFDM-CDMA Waveforms
- Constant-Envelope (CE) Variations
- Questions/Issues with CE-OFDM
- Summary
- References

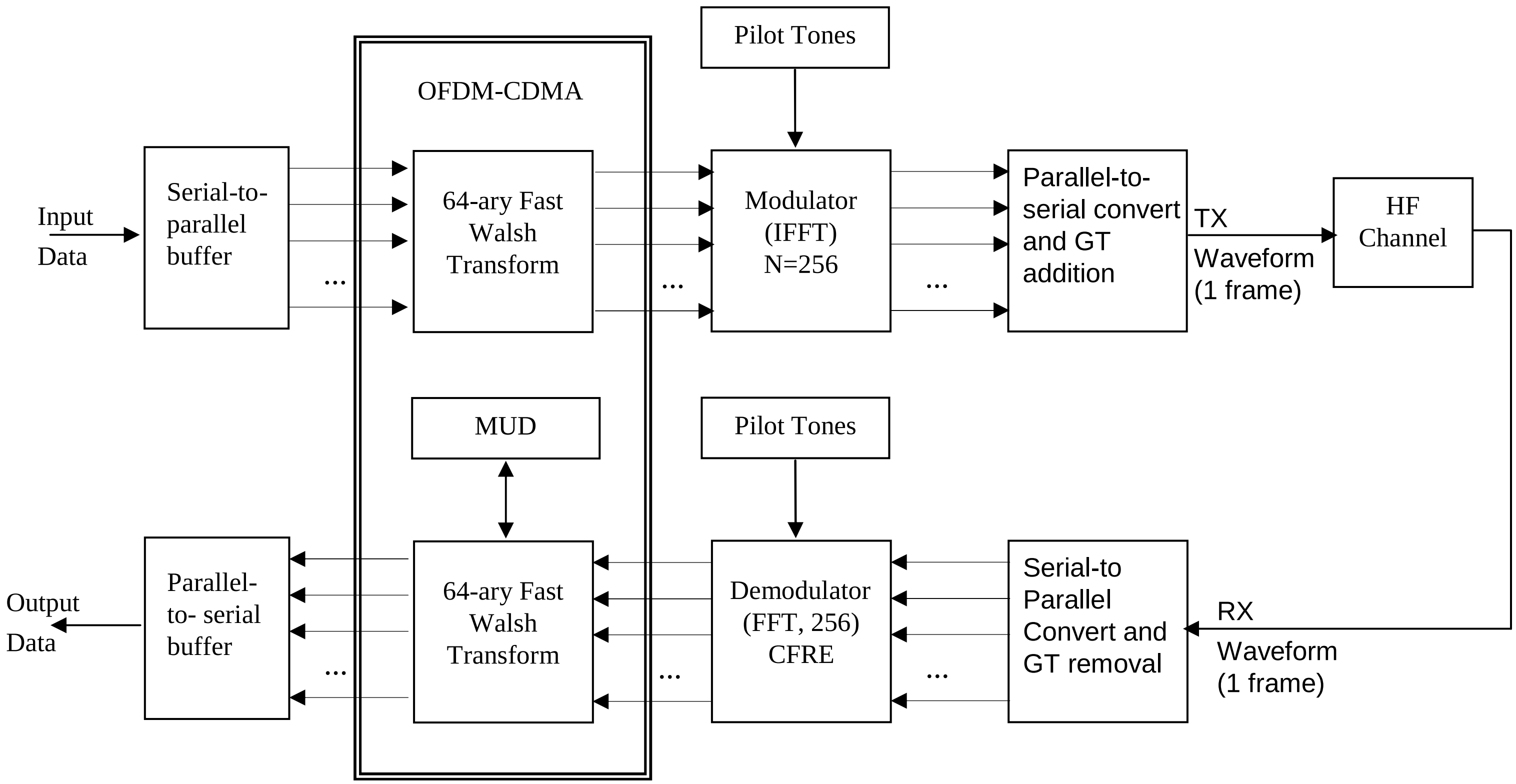
OFDM and OFDM-CDMA Waveforms

- OFDM
  - Orthogonal Frequency Division Multiplexing
  - An OFDM frame is created by transmitting data using N orthogonal tones in parallel
  - Addition of a guard-time removes inter-frame interference
  - Coherent Modulation
    - Equalizer in frequency domain becomes a single complex tap per OFDM tone
  - Differential Modulation
    - No equalizer required
  - IFFT (TX) and FFT (RX) are very efficient signal processing blocks that can be used to generate and demodulate OFDM

OFDM and OFDM-CDMA Waveforms

- OFDM-CDMA
  - OFDM + Code Division Multiple Access
  - OFDM + guard-time reduces equalizer to single complex tap per OFDM data tone
  - CDMA aspect of waveform spreads data across many frequency-domain OFDM tones
  - Additional signal processing required at receiver when multipath/fading present
    - Multi-user detection (MUD)

OFDM and OFDM-CDMA Waveforms



CFRE – Channel Frequency Response Estimate

GT – Guard time

OFDM and OFDM-CDMA Waveforms

- Disadvantage of OFDM and OFDM-CDMA
  - High Peak-power to Average-power Ratio (PAR)
    - Worst case - 10 log10(N)
    - Typical – 10-14 dB for N > 16
  - Requires very linear power amplifier (PA)
    - Class A or Class A-B
    - Distortion and spectral re-growth caused by PA
  - For some applications (i.e. handheld devices, battery powered), Class C amplifiers desired

OFDM and OFDM-CDMA Waveforms

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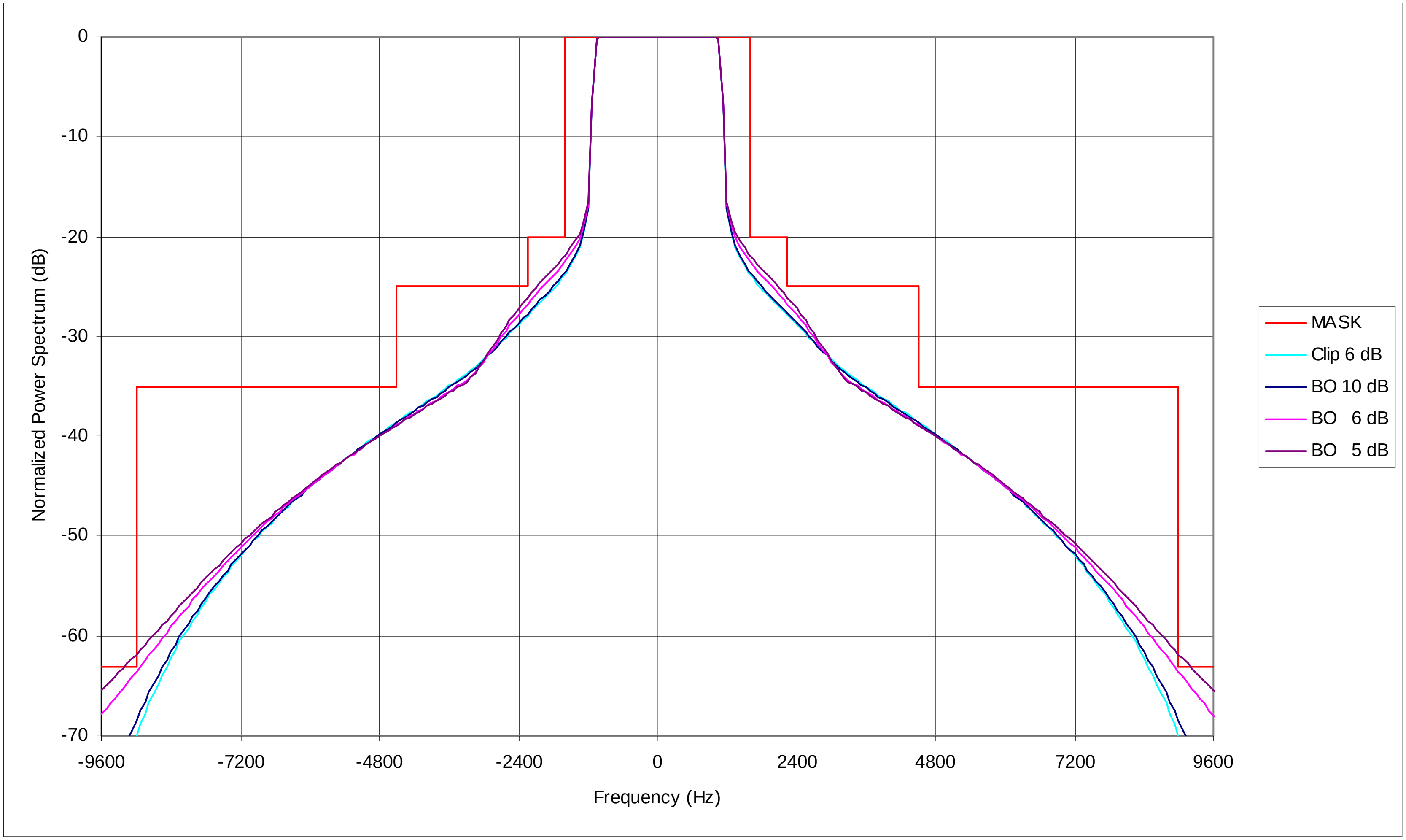
OFDM Spectral Re-growth with Simulated PA



Constant-Envelope (CE) Variations

- CE-OFDM
  - CE-OFDM driven by the desire to use efficient Class C amplifiers
  - Traditional OFDM amplitude-modulates a carrier using output from IFFT
  - Why not phase-modulate the carrier with output from IFFT
    - Result is a constant envelope waveform
  - Researchers include PAR difference when comparing performance
    - For example, from previous figure, OFDM would have a shift of +6 dB in BER curve

Constant-Envelope (CE) Variations

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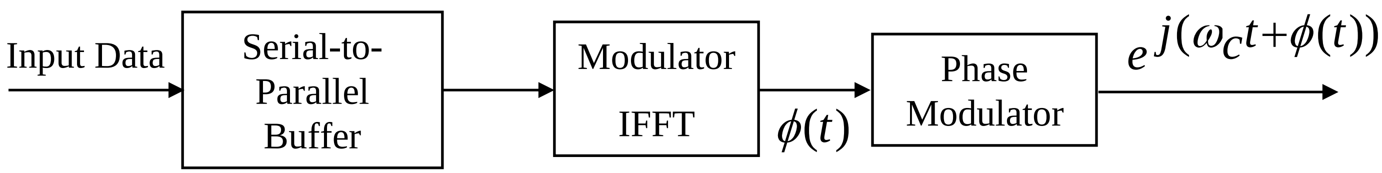
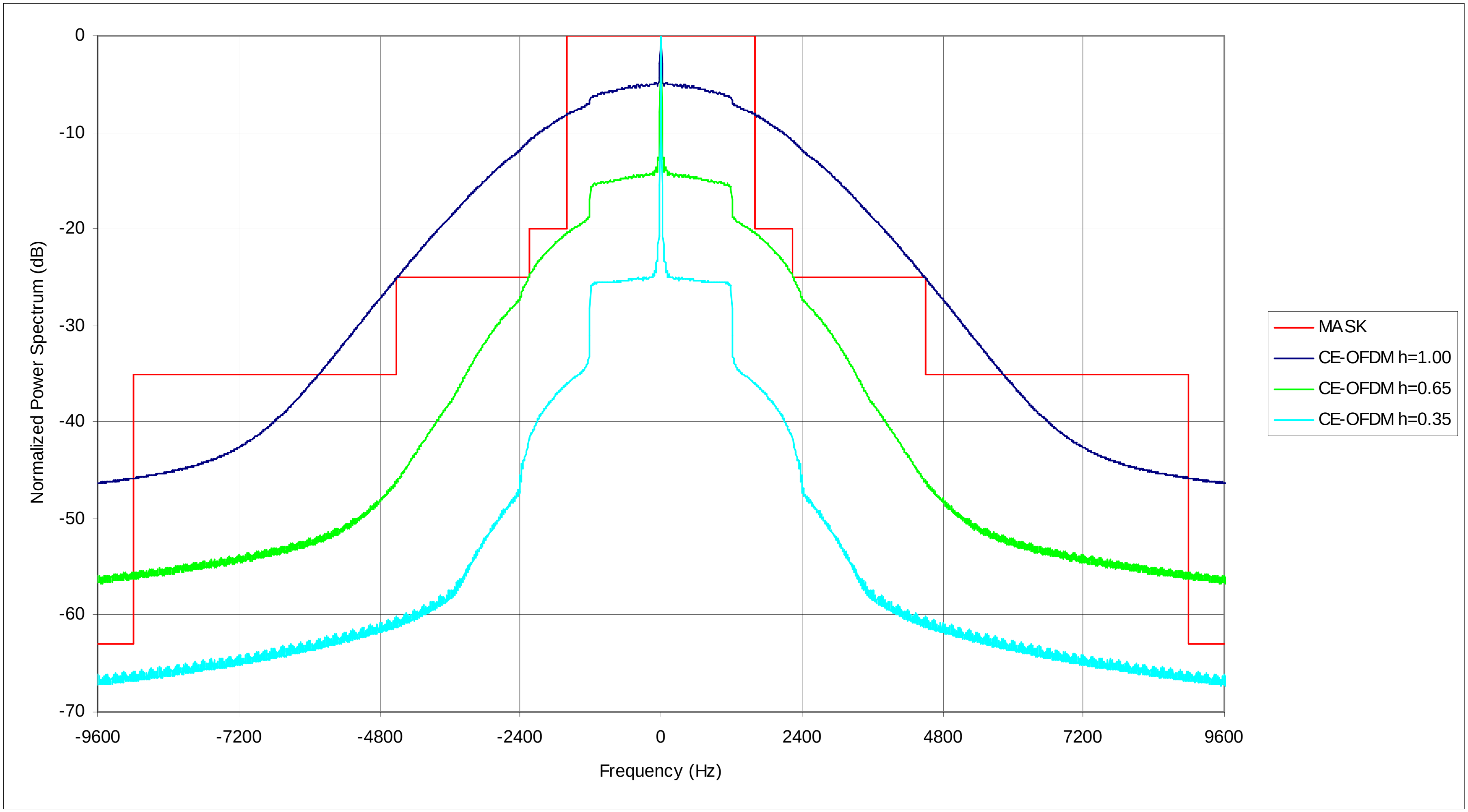


- CE-OFDM requires a real-valued OFDM message signal [1][2]
  - M-ary Pulse-amplitude modulation (MPAM) instead of M-ary phase shift keying (MPSK) and M-ary quadrature amplitude modulation (MQAM)
- Sub-carriers must also be real valued
  - Can use half wave cosines, half wave sines or full-wave cosines and sines
    - Please see references at end of presentation for additional detail on generation of sub-carriers

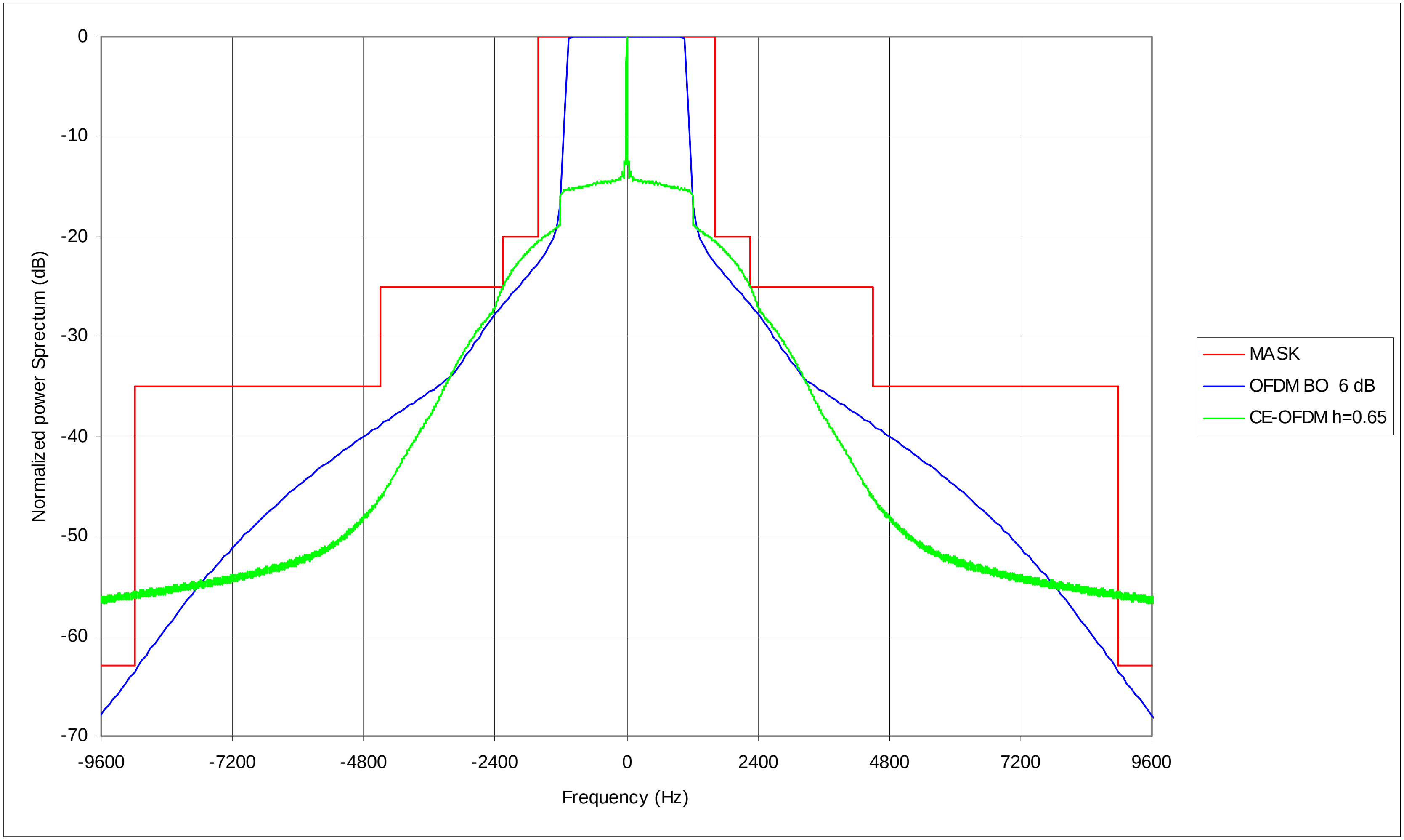
Constant-Envelope (CE) Variations

Spectrum of CE-OFDM as modulation index is varied



Constant-Envelope (CE) Variations

Spectrum of OFDM and CE-OFDM



Constant-Envelope (CE) Variations

- Receive Processing
  - A phase demodulator required before FFT
    - Phase un-wrapper follows phase demodulator to maintain phase continuity
  - To improve performance of phase demodulator, over-sampling by 4x to 8x is recommended
  - Equalizer for multipath/fading channel must be placed before phase demodulator

Questions/Issues with CE-OFDM

- Equalization
  - New techniques must be developed for channel estimation (i.e. traditional OFDM techniques may not work)
  - Requires FFT/IFFT in order to implement
  - Most researchers assume perfect knowledge of channel when presenting results
- Large DC bias in spectrum (Good or Bad ??)
  - Does DC bias affect channel estimation
  - Is CE-OFDM more susceptible to jamming of carrier (i.e. center) frequency
    - Significant energy of waveform close to carrier
  - How does a channel with nulls close to zero (i.e. carrier) affect performance

Questions/Issues with CE-OFDM

- If CE-OFDM must use a real valued modulation (MPAM) and OFDM can use a complex modulation (MQAM), will 6 dB PAR advantage of CE-OFDM really matter
  - Comparing uncoded 16-QAM to 16-PAM @ a BER = 10^{-4}
    - 16-QAM requires 13 dB Eb/No
    - 16-PAM requires 22 dB Eb/No
    - Advantage of 9 dB for 16-QAM
- Modulation index h for CE-OFDM must be selected to meet bandwidth constraints of application
  - Larger h requires wider bandwidth but has better Eb/No performance

Questions/Issues with CE-OFDM

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- Threshold effect similar to FM demodulation
  - Below 10 dB signal-to-noise ratio, performance degrades significantly
- Researchers compare mostly uncoded systems
  - Coded OFDM, OFDM-CDMA and CE-OFDM and CE-OFDM-CDMA must be compared
    - For example, when OFDM was compared to OFDM-CDMA, uncoded performance was significantly better for OFDM-CDMA on multipath/fading channels. When coding was added, difference was much smaller !!
- CE-OFDM patented ??
  - Method and apparatus for constant envelope orthogonal frequency division multiplexing in a wireless system
    - USPTO Patent Application 20060274641.

Summary

- CE-OFDM seems like a promising technique to reduce PAR and allow the use of more efficient class C PAs
- Many questions still remain unanswered in order to determine how well CE-OFDM and CE-OFDM-CDMA will perform on real multipath/fading channels

References

- [1] Steven Thompson, “Constant Envelope OFDM Phase Modulation”, PHD dissertation 2005, UCSD
- [2] Jun Tan, Gordon Stuber, “Constant Envelope Multi-Carrier Modulation”, IEEE Milcom 2002
- [3] C.-D. Chung and S.-M. Cho, “Constant-Envelope Orthogonal Frequency Division Multiplexing Modulation,” in Proc. APCC/OECC, vol. 1, Beijing, Oct. 1999, pp. 629–632.
- [4] M. T. Le and L. Thibault, “Performance Evaluation of CEOFDM for Digital Audio Broadcasting Part II: Effects of HPA Nonlinearities,” IEEE Trans. Broadcast., vol. 44, no. 2, pp. 165–171, June 1998.