PAPR Frequency View for Cognitive Radio Systems

Sajjad Hussain

SUPELEC
Signal Communications & Embedded Electronics

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SUMMARY

- Non-linearities and PAPR Problem in Cognitive Radio (CR) systems
  - OFDM and Software Radio signal equivalence
  - Cognitive Radio systems : Dynamic Spectrum Access

- PAPR Frequency Domain Interpretation in CR
  - Free spectrum access under PAPR metric constraint
  - PAPR reduction methods based on adding signals in the frequency domain (tone reservation, ...)

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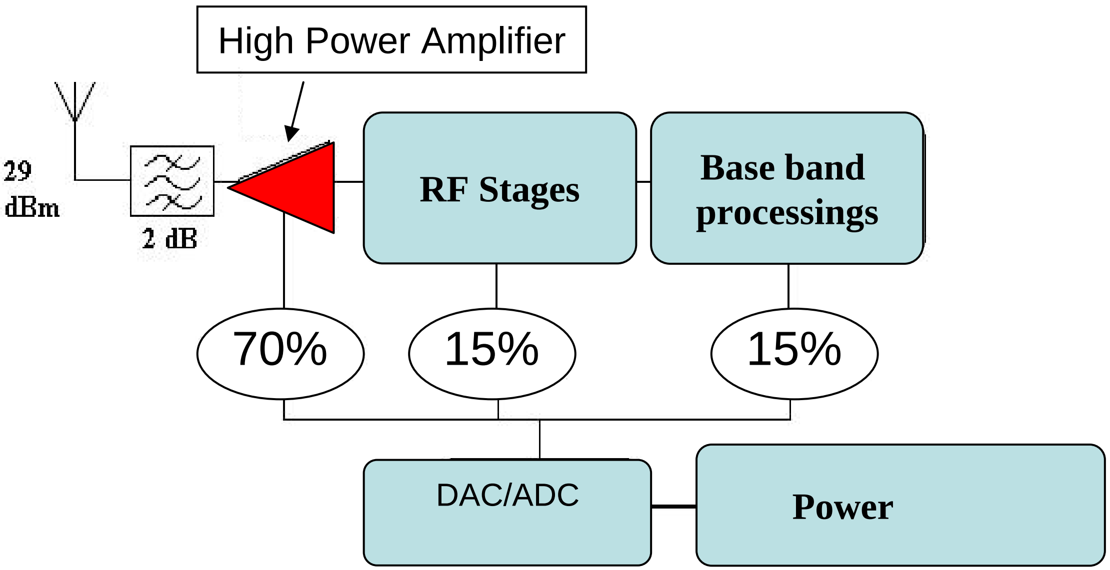
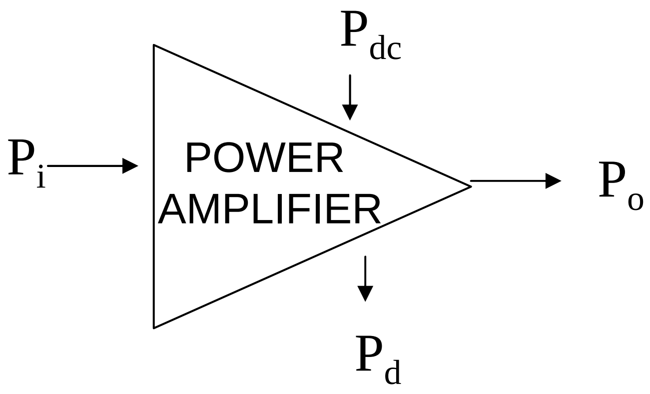
Power Amplifier Characteristics

A 2.5G terminal power budget:

- Power : A key factor in telecommunications
- 60-70 % of power consumption due to HPA*





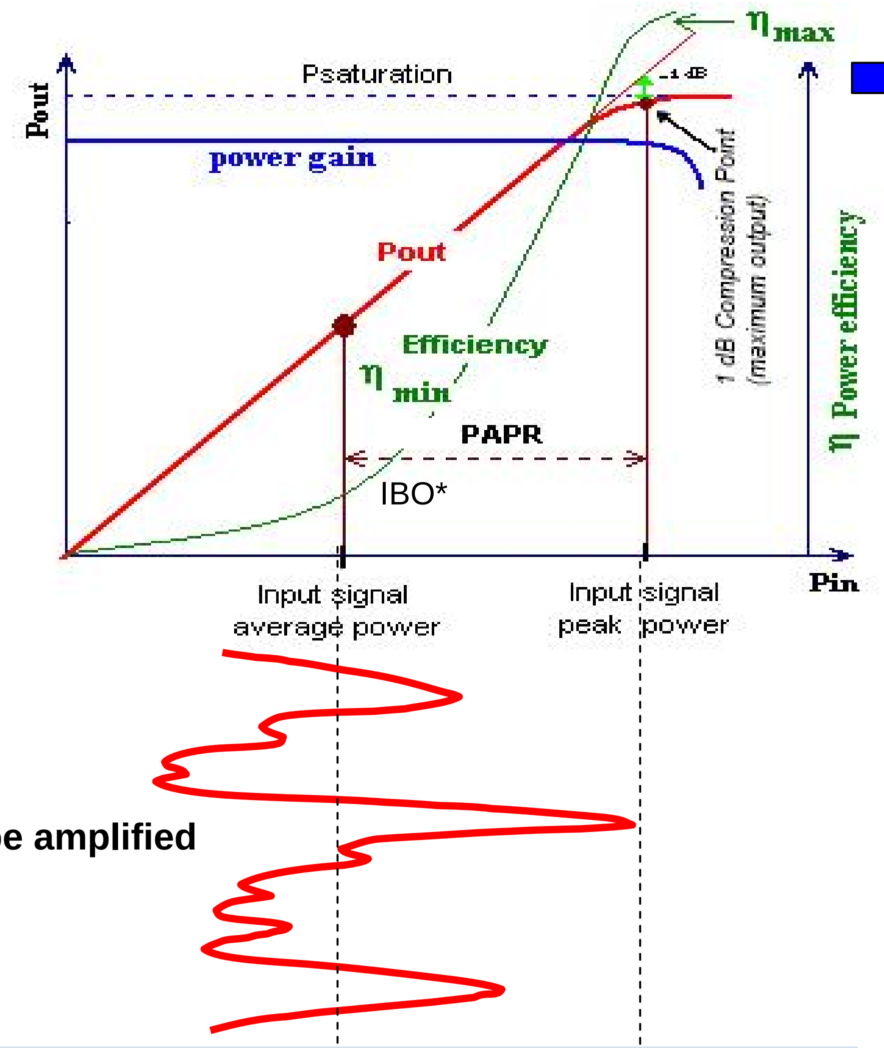
Power budget :

$$P_i + P_{dc} = P_o + P_d$$

Power efficiency : $\eta = \dfrac{P_o}{P_{dc}}$

* HPA : High Power Amplifier

Power Amplifier Efficiency



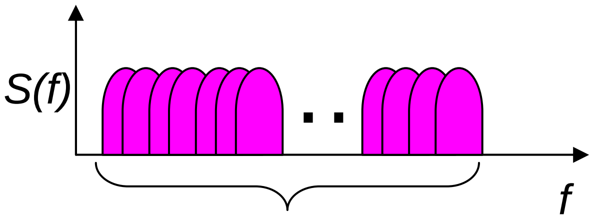
Non linear distortions

Signal to be amplified

* IBO : Input Back Off

OFDM and SWR

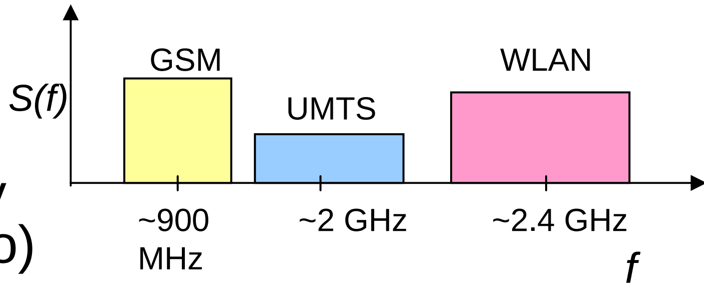
- OFDM is a multiplex of modulated carriers.
  - Multicarrier nature of OFDM causes large power fluctuations.



OFDM frequency view

- SWR is also a multiplex of modulated carriers
  - Case 1 : Mono Standard signals ($\Delta f = cnst$)
  - Case 2 : Multi Standard signals ($\Delta f \neq cnst$)

  => SWR signal also demonstrates large power fluctuations.



SWR frequency view

- Power fluctuations are generally described by the term PAPR (Peak to Average Power Ratio)
  - PAPR=maximum power/ average power
- As PAPR is a random variable so it is presented by its cumulative distribution function,

$$CCDF = Pr[PR > PR_0]$$

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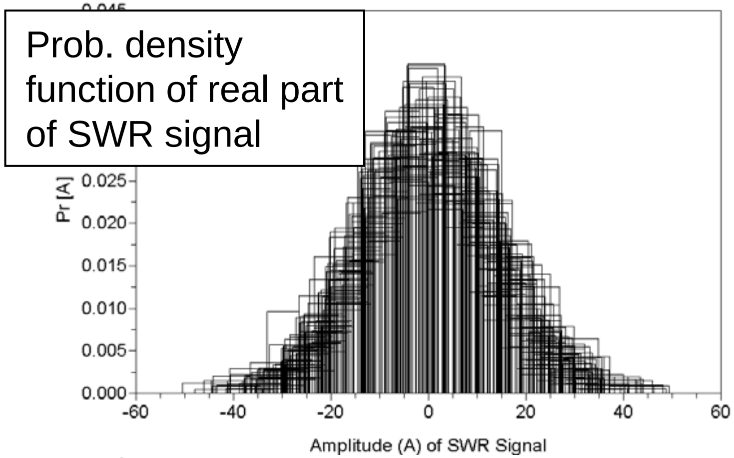
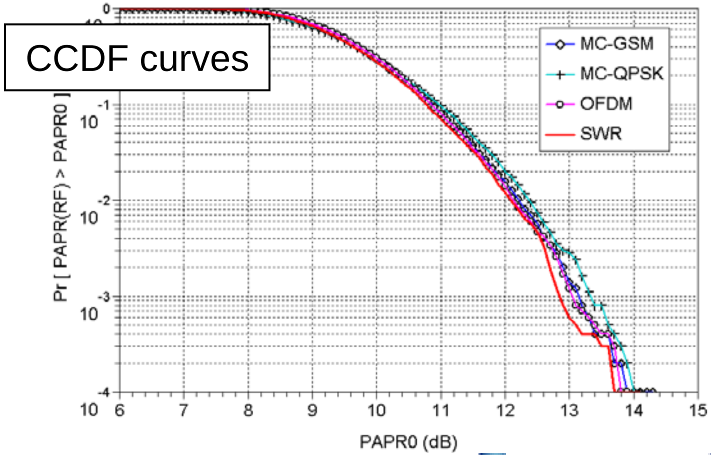
SWR and OFDM : The Gaussian Equivalence

For signals with large number of modulated sub-carriers N, we have shown the equivalence between OFDM and SWR PAPR distribution.

SWR=MC-GMSK+ MC-QPSK+OFDM
with N=64 L=4 for all modulations





SWR signal follows classical OFDM PAPR distribution curve:

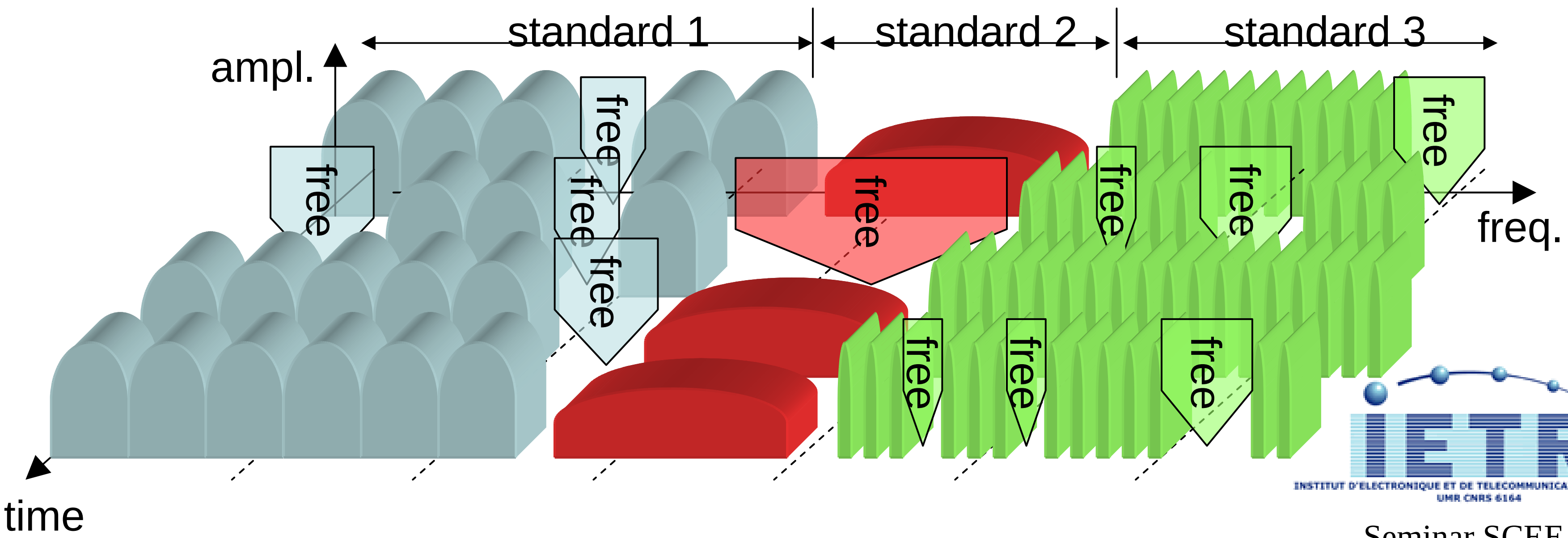
$$Pr[PR \geq PR_0] \approx 1 - e^{-\sqrt{\frac{\pi}{6}}N\sqrt{PR_0 e^{-PR_0}}}$$

Conclusions :
Equivalence between OFDM and SWR motivated to use same analysis and the same methods for PAPR mitigation as for OFDM.

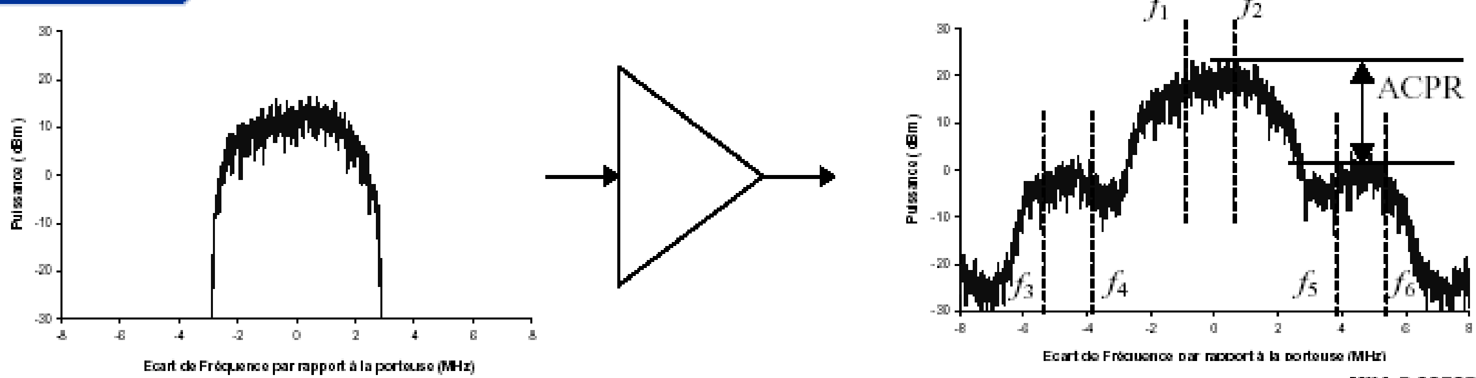
Cognitive Radio and Dynamic Spectrum Access

- Real time modification of the physical layer parameters (link adaptation).
- Insert spectrum (tones) in between standards or inside the standards (opportunistic communication).
  - Find hole, check if useful and then insert the tones

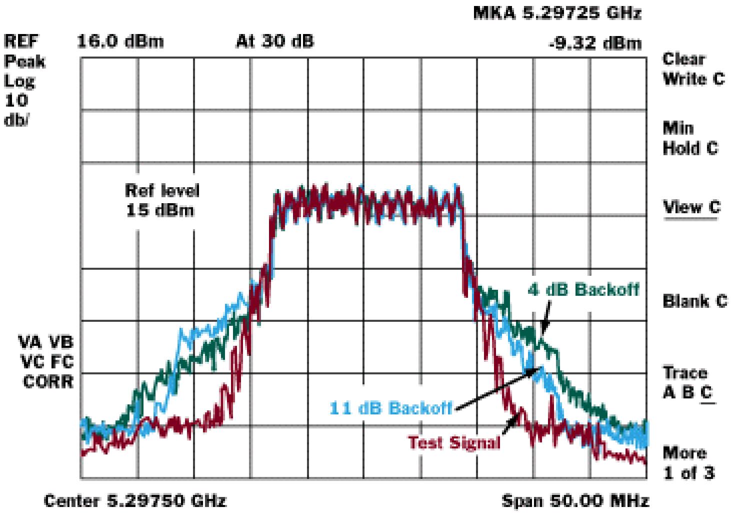
  => Global PAPR is modified



Cognitive Radio and Dynamic Spectrum Access



$$ACPR_{dB} = 10 \cdot \log \frac{\int_{f_1}^{f_2} P(f)df}{\int_{f_3}^{f_4} P(f)df + \int_{f_5}^{6} P(f)df}$$



Spectrum access should not increase the out of band power level to avoid interference with other signals

Dynamic Spectrum Access & PA Behaviour

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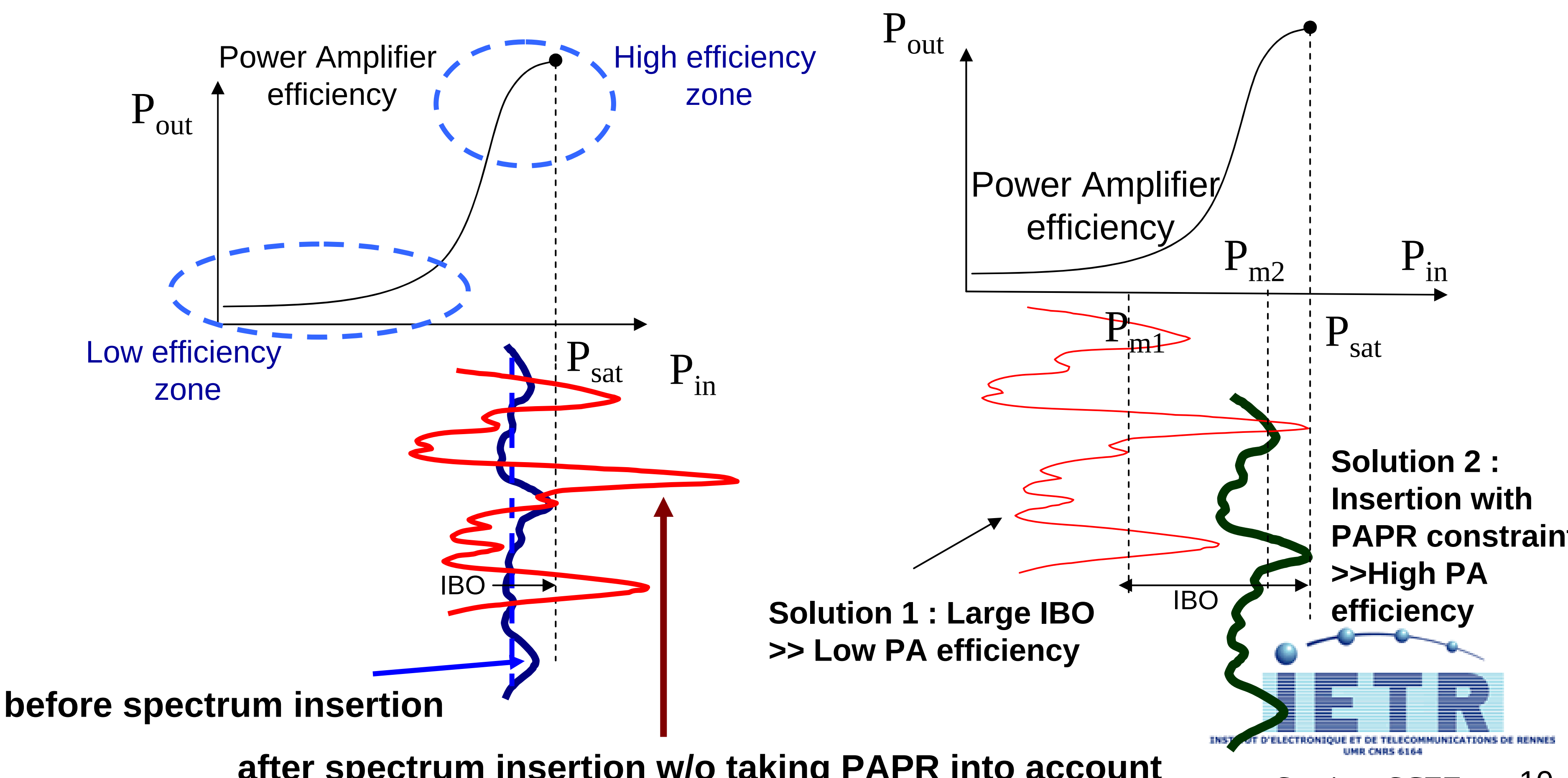
- PAPR mitigation solutions after spectrum access



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  - OFDM and Software Radio signals equivalency
  - Cognitive Radio systems : dynamical Spectrum Access

- PAPR Frequency Domain Interpretation
  - Free spectrum access under PAPR metric constraint
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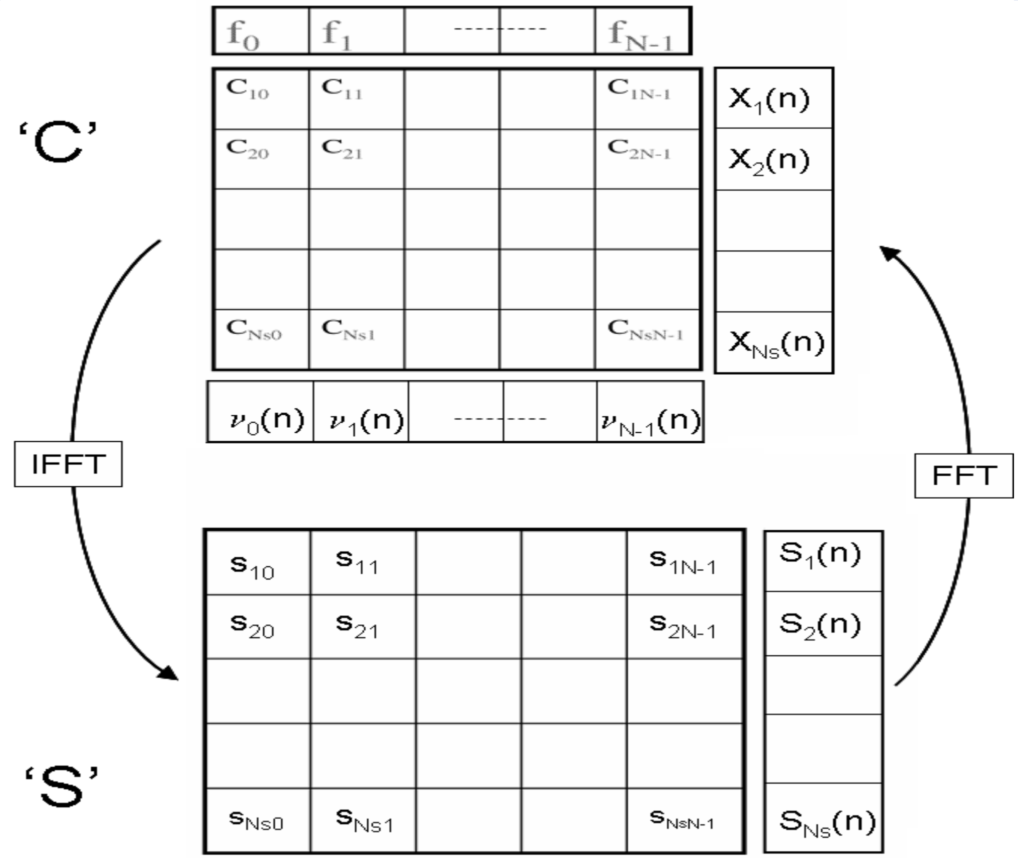
Frequency Domain PAPR Interpretation (1/7)

- In OFDM frequency symbols 'C' are tabulated as carrier per carrier.
- If Ns (Number of OFDM symbols) increases, PAPR approches theoretical upper bound.
- Rows and columns interchangeable for PAPR calculations.



$$\sum_{r=1}^{N_s} \sum_{c=1}^{N} C_{c,r} \exp(\iota 2\pi rc/N) = \sum_{c=1}^{N} \sum_{r=1}^{N_s} C_{c,r} \exp(\iota 2\pi rc/N)$$

Goal : Express (time) PAPR vs individual carrier PAPR as each carrier PAPR being very easy to compute

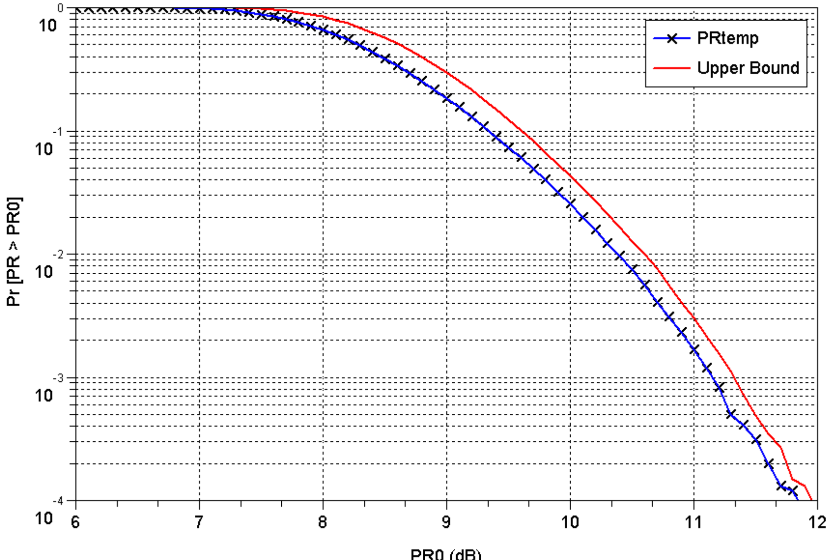
Frequency Domain PAPR Interpretation (2/7)

$$PR_{N_s}(S(n)) \leq \frac{(\sum_{k=1}^{N} P_m(k) \times PR_{f_k}) + \max_{k\in K}(\max_{j\in J}(\lambda(j,k)))}{\sum_{k=1}^{N} P_m(k)} \quad (1)$$

where

$$\lambda(j,k) = \sum_{p=1}^{N} C_{j,p} \sum_{p' \neq p} \overline{C_{j,p'}} e^{2i\pi \frac{k(p-p')}{N}}, j \in J, k \in K.$$

- It demonstrates that PR_{temp} is upperbounded by relation (1) which depends only on frequency components.



Upperbound and PR_{temp} distribution for OFDM

16 QAM
64 Carrier
OFDM Signal

Frequency Domain PAPR Interpretation (3 / 7)

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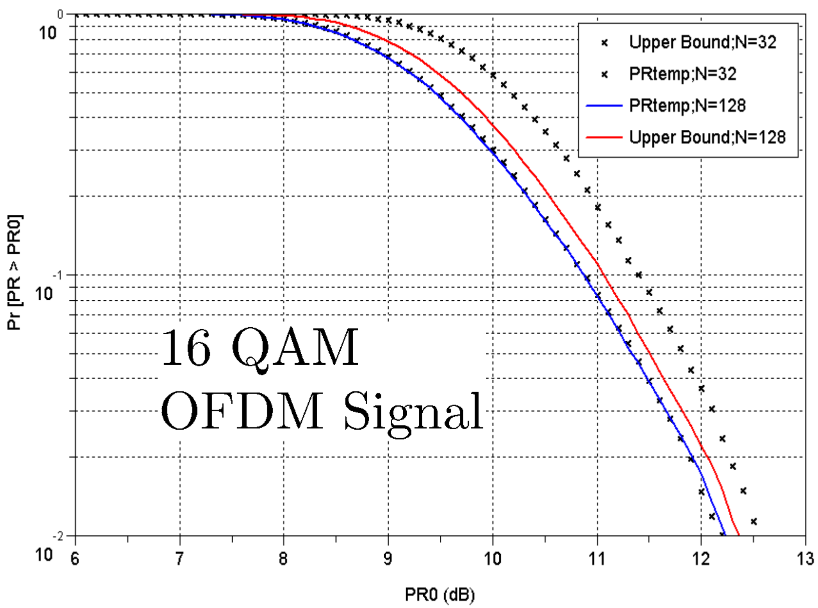
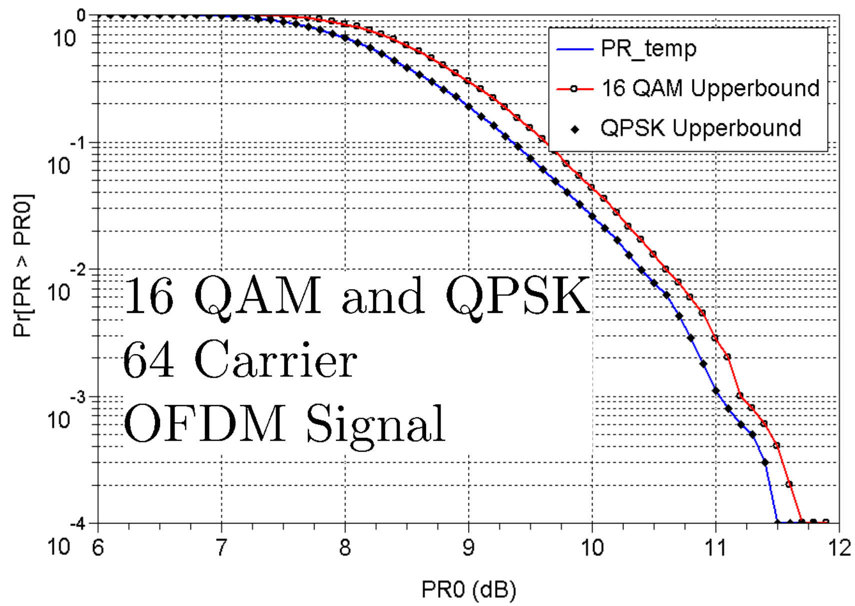
- FFT size and modulation type effects

FFT size effect on OFDM upper bound



Upperbound approaches PR_{temp} when N becomes large

Modulation type effect on OFDM upper bound



Upperbound = PR_{temp} for PSK modulations

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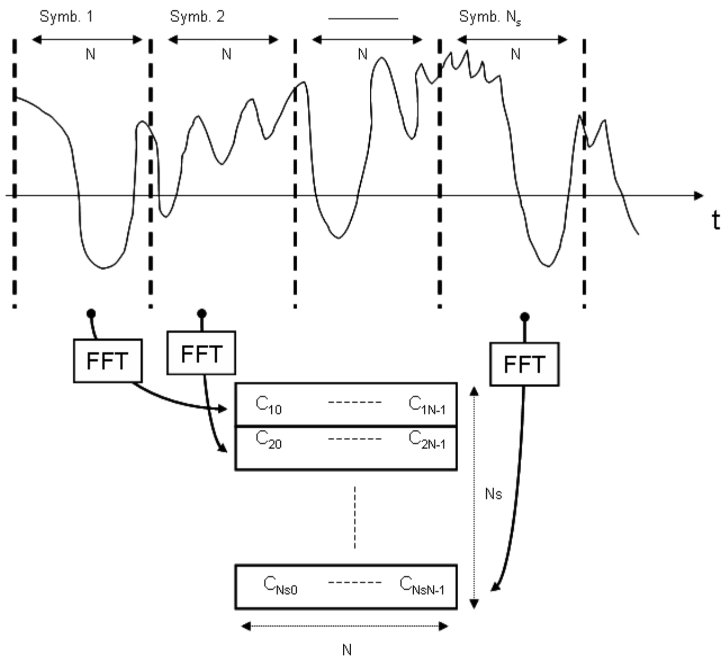
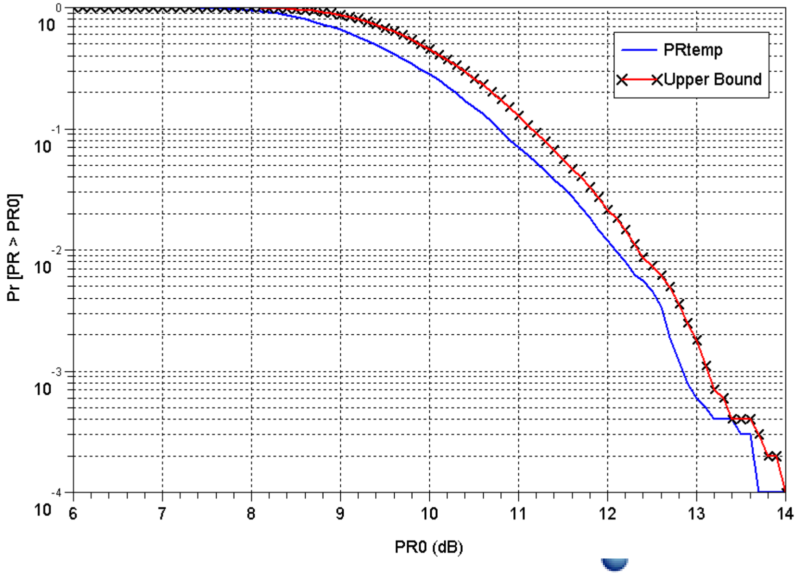
Frequency Domain PAPR Interpretation (4/7)

- Application to any SWR signals
  - SWR signal is sliced into pieces of FFT size
  - FFT is taken on these pieces to get 'C'
  - Eq. (1) is applied on 'C' and uppper bound is obtained



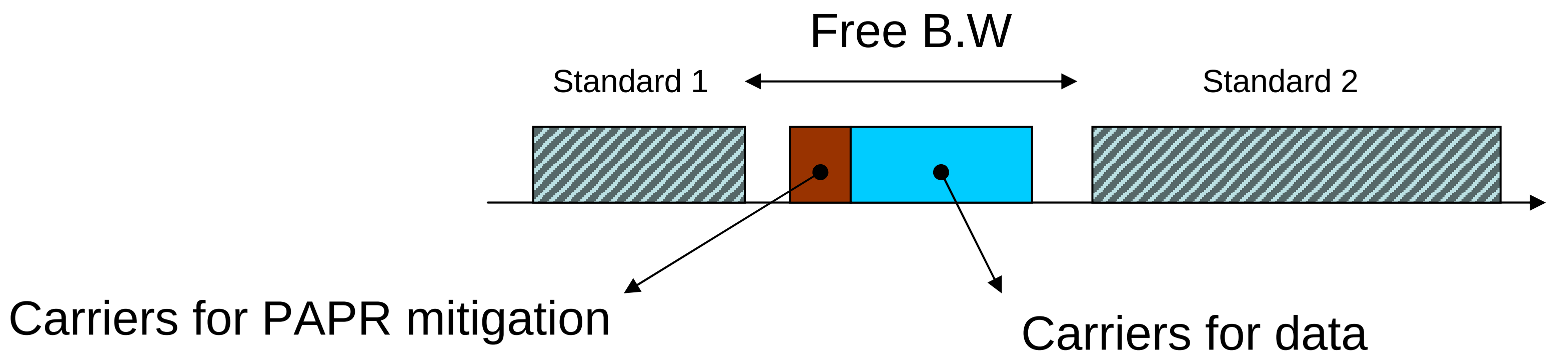


SWR=MC-GMSK+ MC-QPSK+OFDM
with N=64 L=4

Frequency Domain PAPR Interpretation (5 / 7)

-With the help of this view we can :

- Estimate the spectrum access influence on global PAPR with the help of individual frequential PAPR
- Optimize some of these added carriers for PAPR mitigation (while the others to transmit useful data)



Possible methods : TR, Geometrical tone adding method [1]

(1) D Guel, J Palicot, Y Louët, "*A Geometric Method for PAPR Reduction in a Adding Signal in context for OFDM Signals*", International Conference on Digital Signal Processing, DSP 2007, 1-5 July 2007, Cardiff, UK

Frequency Domain PAPR Interpretation (6 / 7)

- Added Carrier Effect on PAPR Upper Bound

$$PAPR_{N_s}(S(n)) \leq PAPR_{init} + PAPR_{added}$$
$$PAPR_{init} = PAPR_p$$
$$PAPR_{added} = PAPR_s + PAPR_m$$

with

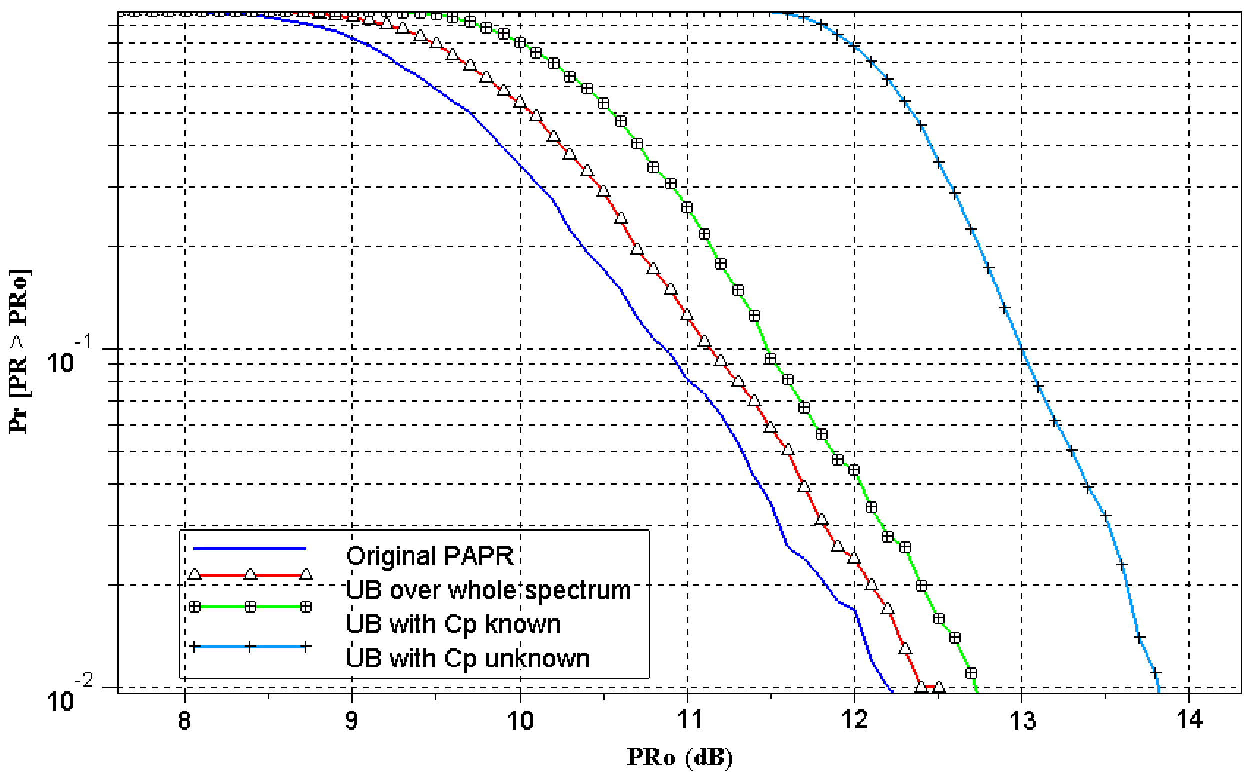
$$PAPR_p \approx \frac{\max_{k\in K}(\max_{j\in J}(|\sum_{p\in P} C_{j,p}e^{i2\pi kp/N}|^2))}{\sum_{k=1}^{N} P_m(k)}$$
$$PAPR_s \approx \frac{\max_{k\in K}(\max_{j\in J}(|\sum_{s\in S} C_{j,s}e^{i2\pi ks/N}|^2))}{\sum_{k=1}^{N} P_m(k)}$$
$$PAPR_m \approx \frac{\max_{k\in K}(\max_{j\in J}(2|\sum_{p\in P} C_{j,p}e^{i2\pi kp/N}||\sum_{s\in S} C_{j,s}e^{i2\pi ks/N}|))}{\sum_{k=1}^{N} P_m(k)}$$

where
$p \in P$: Primary carriers
$s \in S$: Secondary carriers

Frequency Domain PAPR Interpretation (7/7)

•With limited spectral knowledge of primary user:

$$PAPR_{added} \leq \frac{\max_{k\in K}(\max_{j\in J}(|\sum_{s\in S} C_{j,s}e^{i2\pi ks/N}|^2 + 2.N_p.|C_{p,max}|\sum_{s\in S} C_{j,s}e^{i2\pi ks/N}|))}{\sum_{k=1}^{N} P_m(k)}$$



$N_p = 62$

$N_s = 4$ QPSK symbols

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Conclusion

- Spectrum access in CR should be:
  - performed taking care of the amplification problems

- PAPR frequency domain view would help in:
  - Free spectrum access under PAPR metric constraint.
  - Application of PAPR reduction methods based on adding signals in the frequency domain (tone reservation, ...).

Thank you !!!

Questions???