CMT 2019

le cnam

The challenges of future IoT waveforms

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3GPP
release 13 (2016)
release 14 (2017)
release 15 (2018)
release 16 (2019)
release 17 (2020)

5G markets

eMBB
(Enhanced Mobile BroadBand)

Throughput > 10 Gbits/s

mMTC
(massive Machine Type Communications)

Battery Life > 10 years

URLLC
(Ultra Reliable Low Latency Communications)

Latency < 1 ms

So many objectives

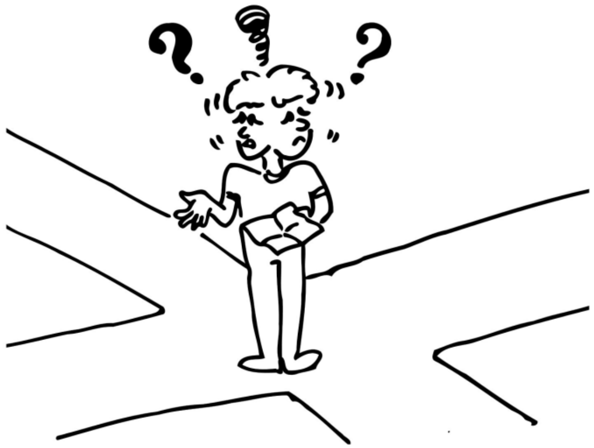
- Very High Throughput
- High Reliability and Low Latency
- Low Power Consumption

- Opportunistic Transmissions
- Unsynchronized Transmissions
- Idle Mode and Fast Wake Up
- Millimeter Waves
- Reconfigurable Antennas
- Indoor Localization
- Massive MIMO
- New Coding Scheme for short packets
- Non Orthogonal Multiple Access (NOMA)
- Pilot Free Synchronization
- Blind Channel Estimation
- …

5G waveform

- So many proposals !
  - CP-OFDM
  - SC-OFDM
  - f-OFDM
  - BF-OFDM
  - FMT
  - **WOLA**
  - UFMC
  - GFDM
  - **FBMC-OQAM**
  - FFT-FBMC

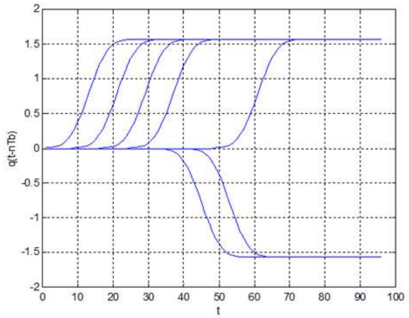
- NB-IoT
- LTE-M
- **LoRa**
- SigFox



Overview

- A short review of mobile radio waveforms
- Short focus on WOLA, FBMC-OQAM and LoRa
- Some power amplification challenges
- Blind estimation

2G waveform



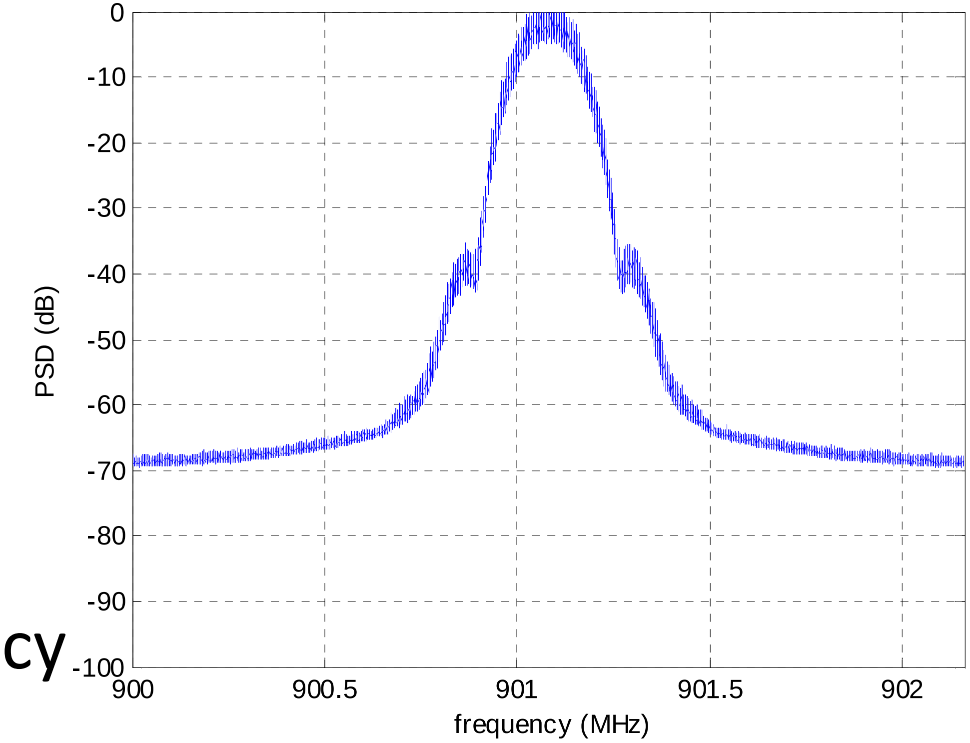
- GMSK (CPFSK ½)

☺

  – Constant Envelope
  – Low side lobes
  – Low cost technology

☹

  – Low spectral efficiency (1bit/s/Hz)



P. Chevalier, F. Pipon, "New insights into optimal widely linear array receivers for the demodulation of BPSK, MSK and GMSK signals corrupted by non circular interferences - Application to SAIC", IEEE Trans. Signal Processing, Vol 54, N°3, pp. 870-883, March 2006.

3G waveform

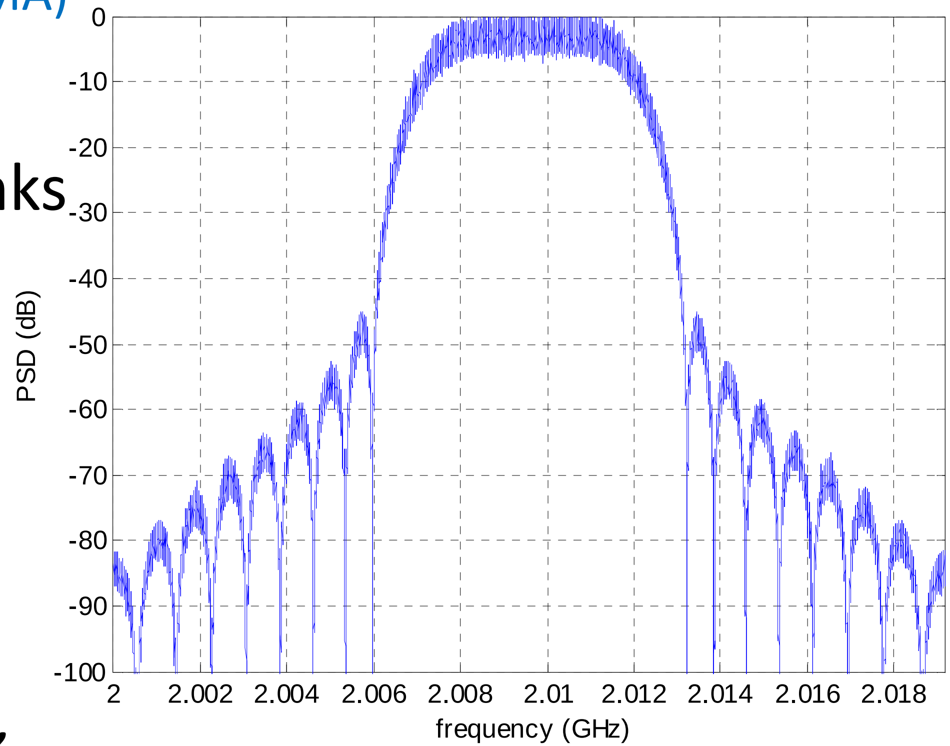
- Filtered M-QAM (and CDMA)

☺

- – Spectral efficiency (thanks to M-QAM)
- – Good spectral location (thanks to roll-off)

☹

- – Interferences (CDMA)
- – *(Non constant Envelope, Down Link)*



4G waveform

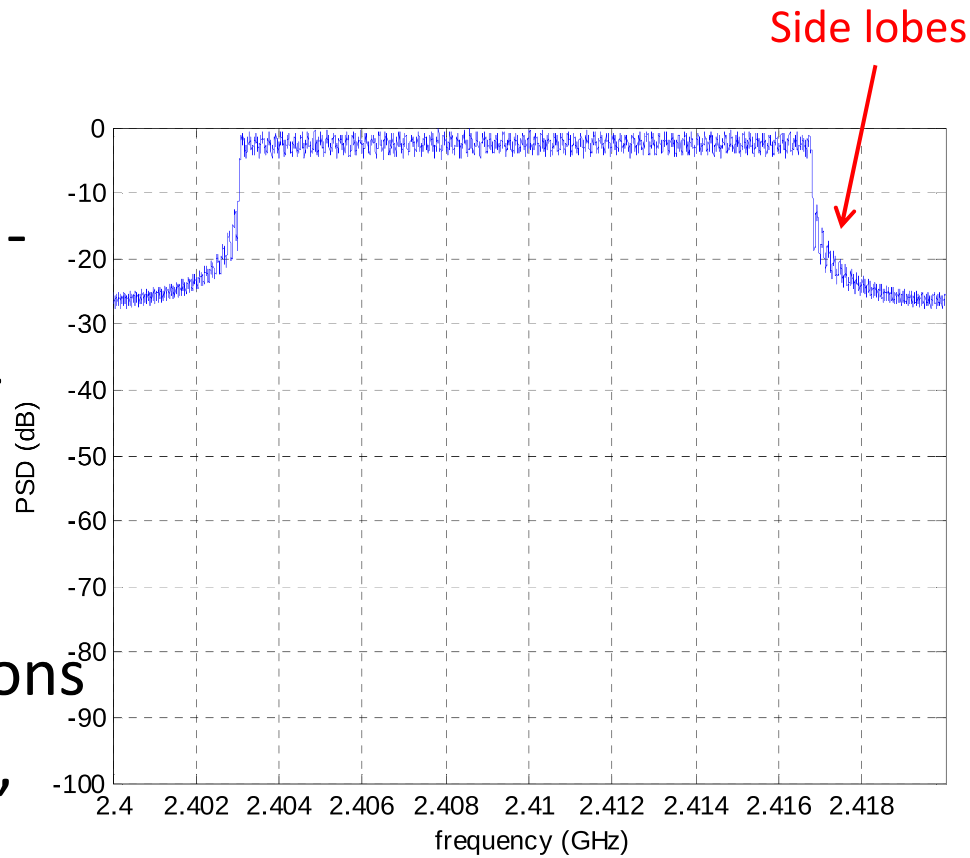
- CPOFDM, M-QAM

☺

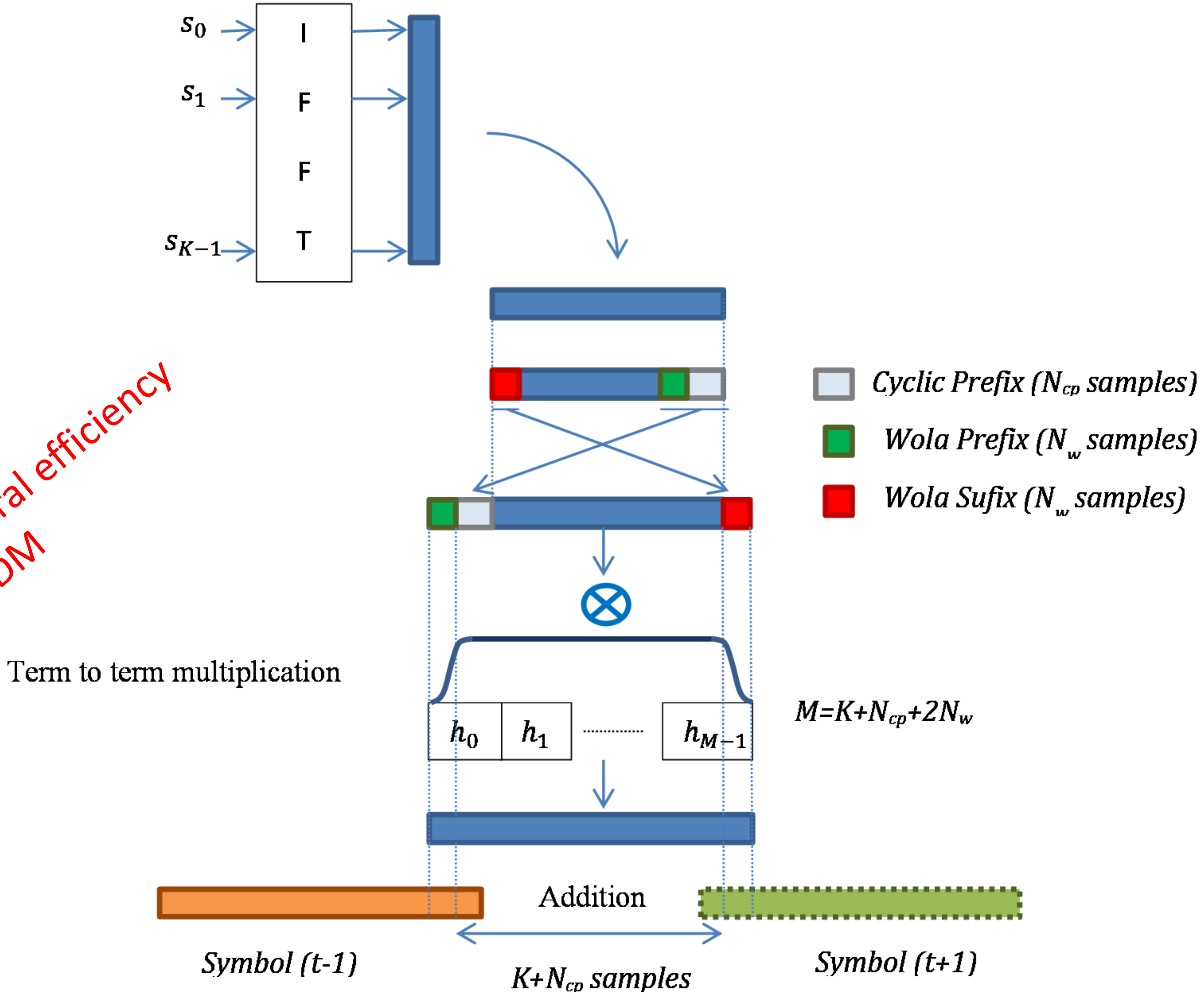
  - Spectral efficiency of M-QAM modulations
  - Easy to implement (FFT and Cyclic Prefix)

☹

  - Side lobes, OOB emissions
  - Non constant Envelope, PAPR



WOLA (Weighted OverLap and Add)



Same spectral efficiency as CP-OFDM

WOLA (Weighted OverLap and Add)

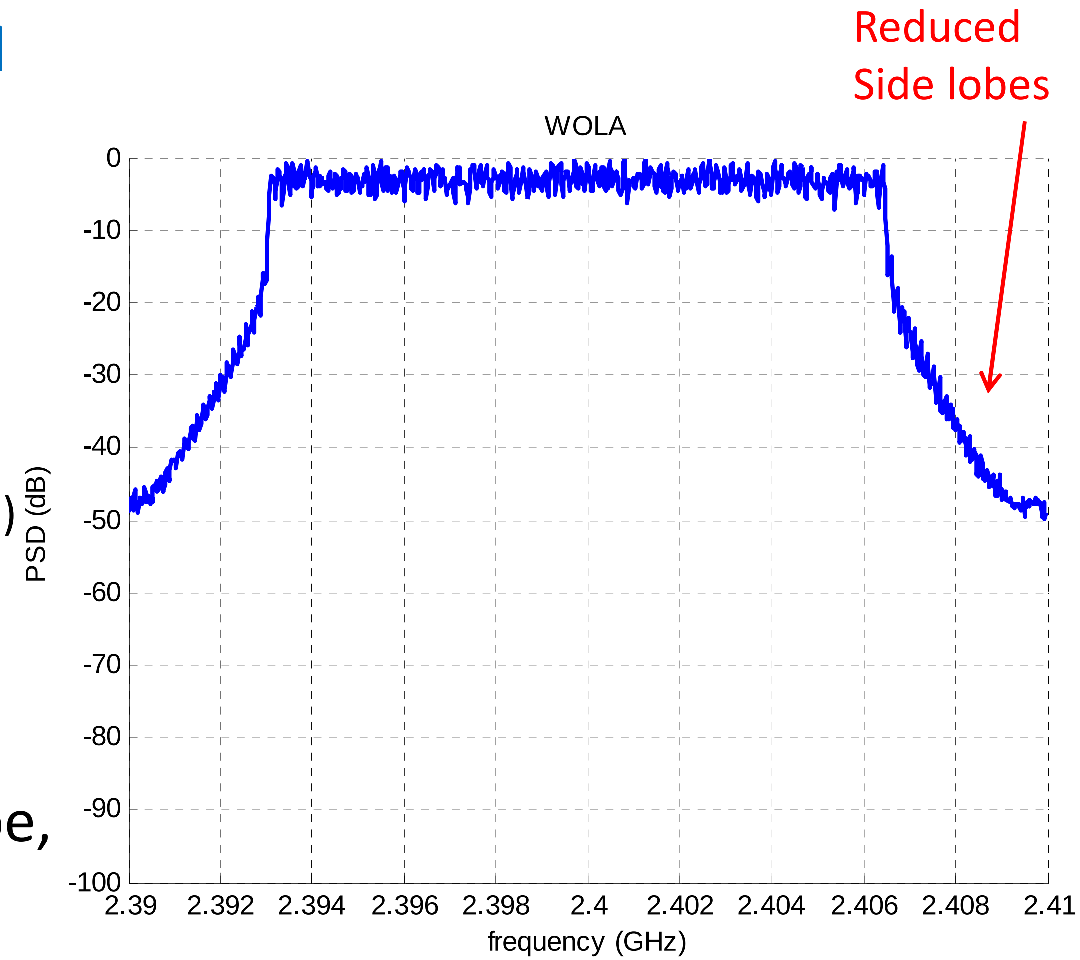
- WOLA OFDM, M-QAM

☺

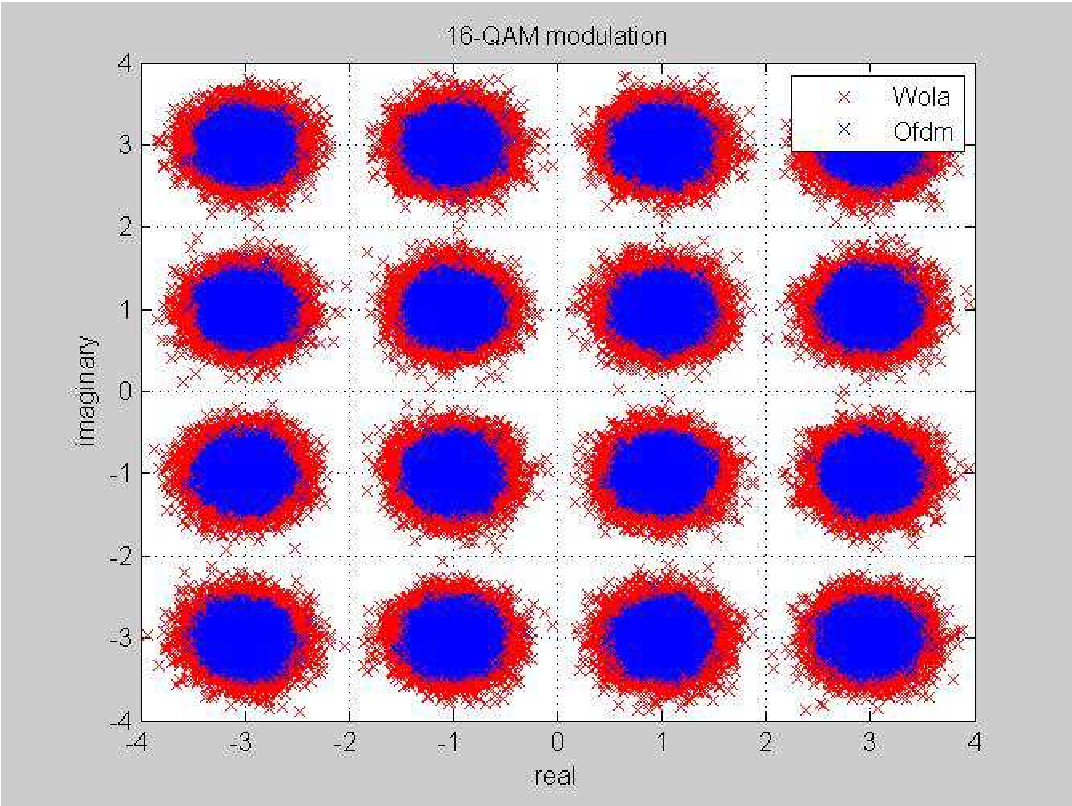
– Reduced Side Lobes
– Spectral efficiency of M-QAM modulations
– Easy to implement (FFT, Cyclic Prefix, Multiplication)
– Can be demodulated by a CP-OFDM receiver

☹

– Non constant Envelope, PAPR



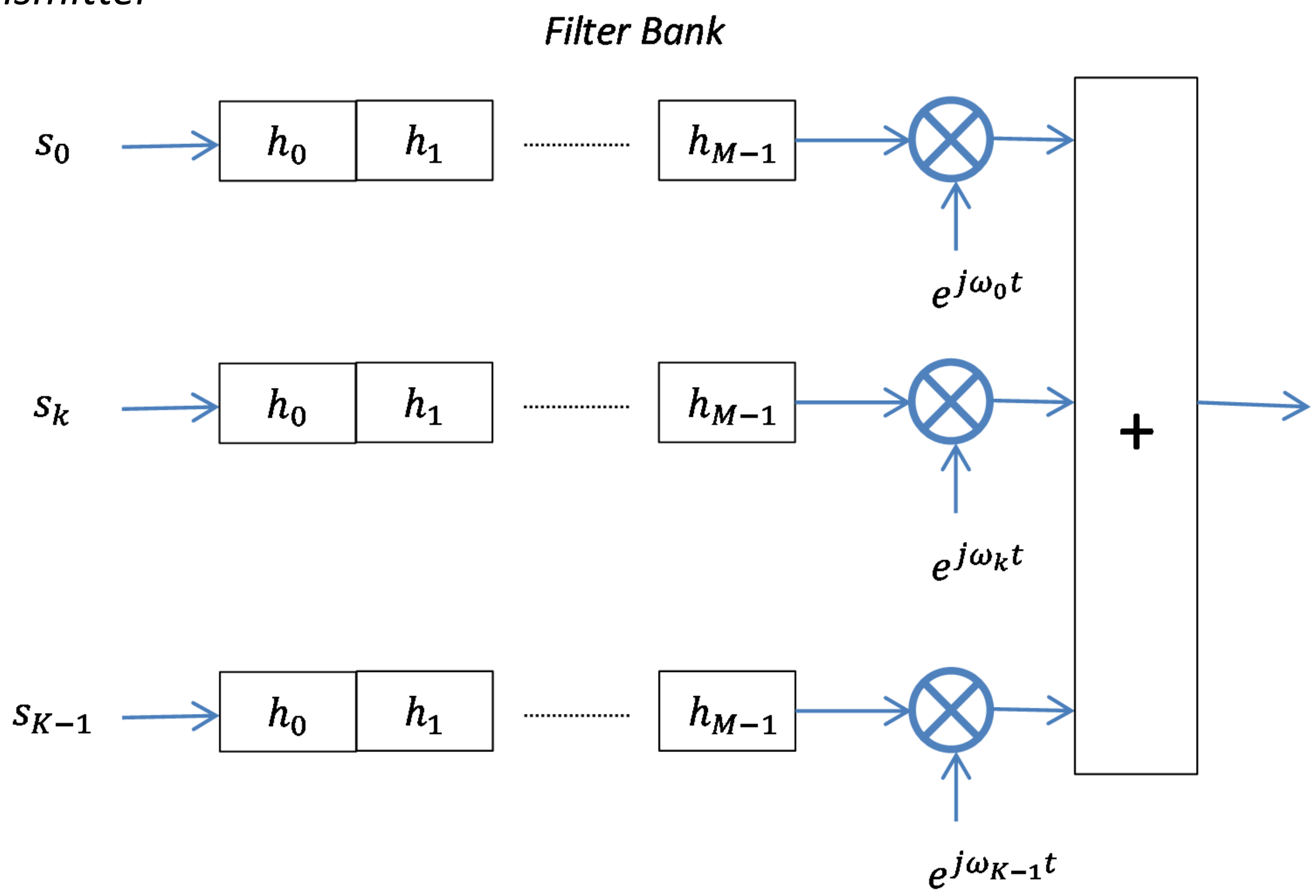
WOLA (Weighted OverLap and Add)



Received with a CP-OFDM receiver

FBMC-OQAM (Filter Bank MultiCarrier)

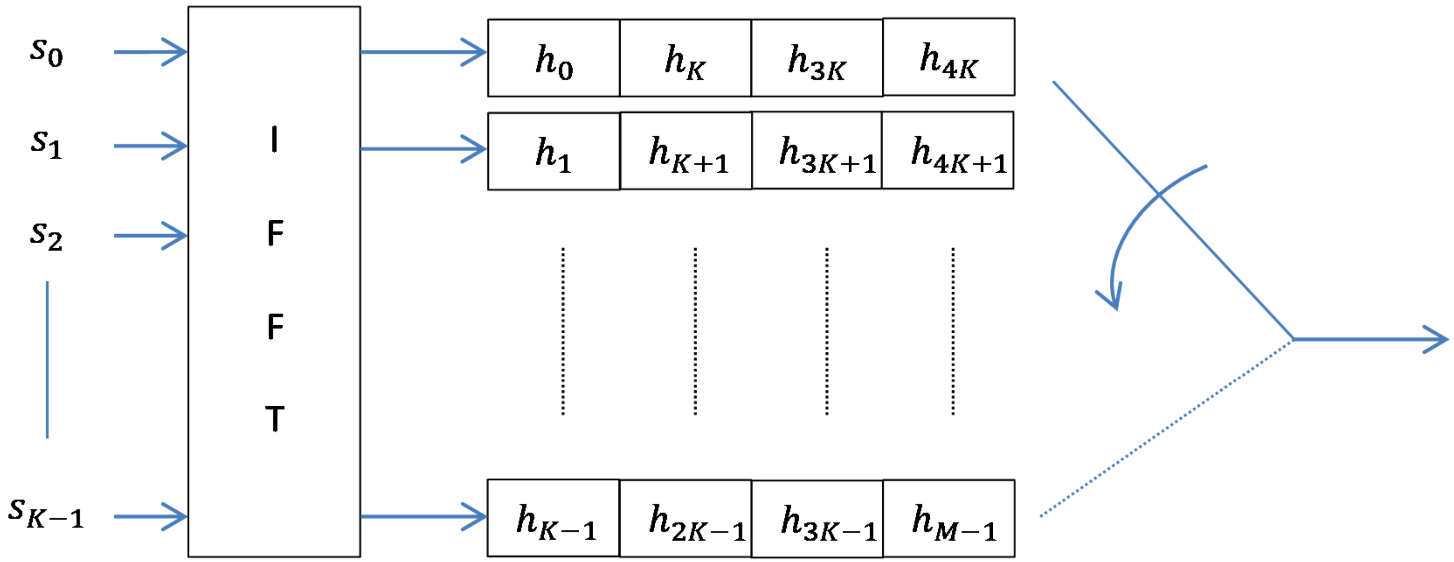
Transmitter



M. Bellanger et al. "FBMC physical layer : a primer", http://www.ict-phydyas.org/teamspace/internal-folder/FBMC-Primer_06-2010.pdf

FMBC - Polyphase Approach -

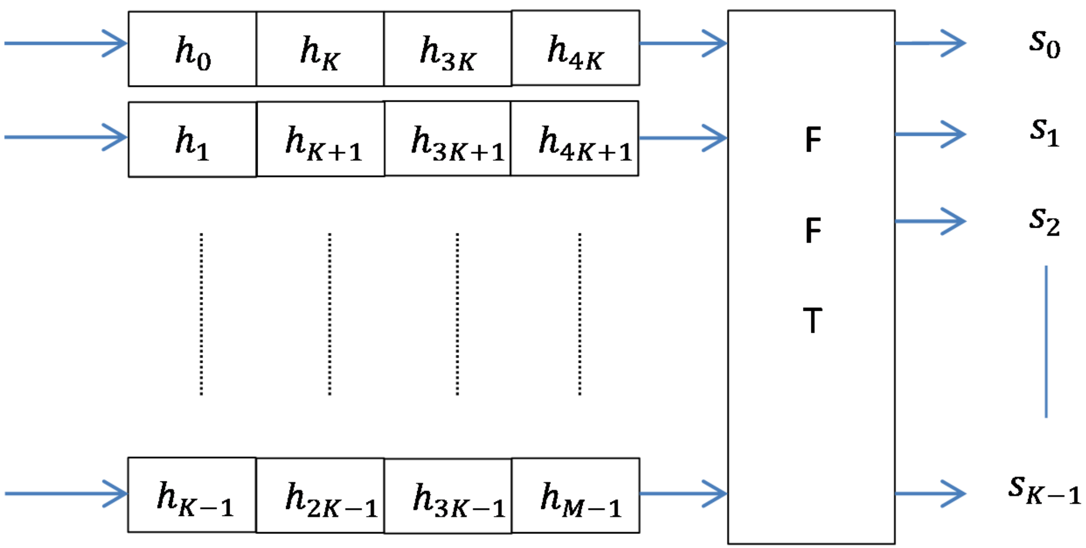
Transmitter



$M = 4K$

FBMC – Polyphase Approach -

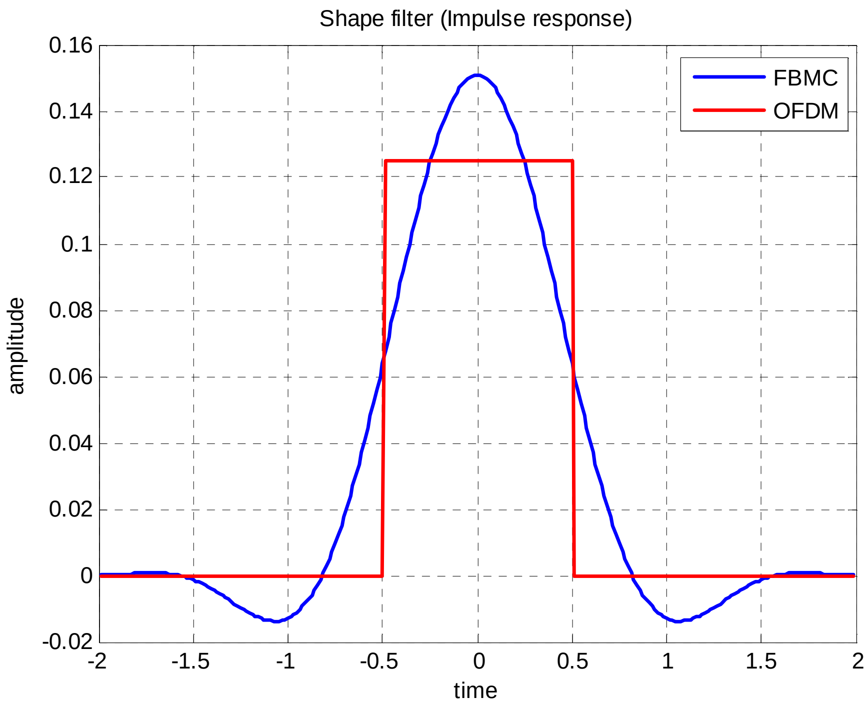
Receiver

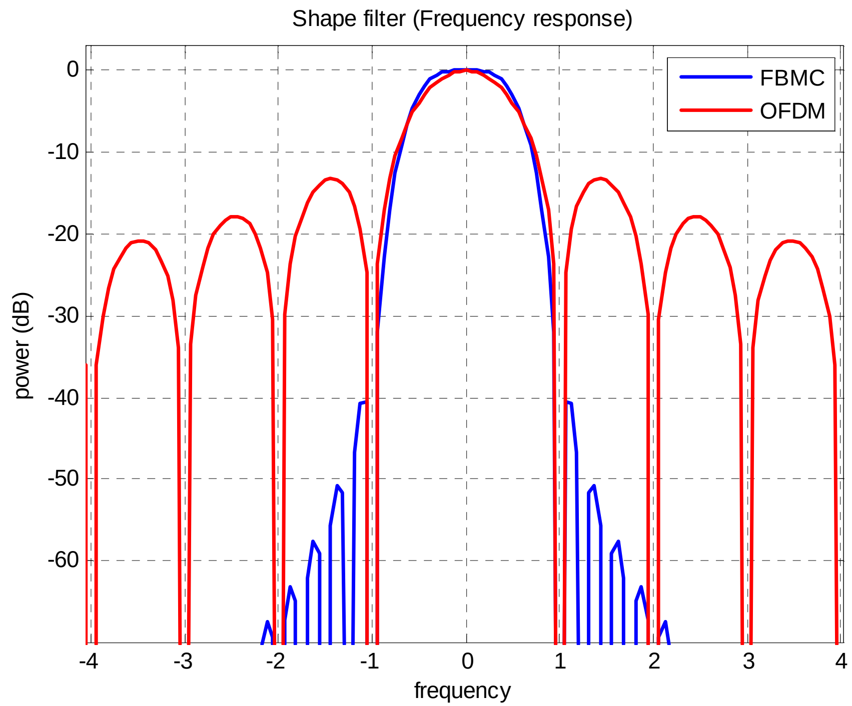


$M = 4K$

FBMC-OQAM, Phydyas Filter

http://www.ict-phydyas.org/





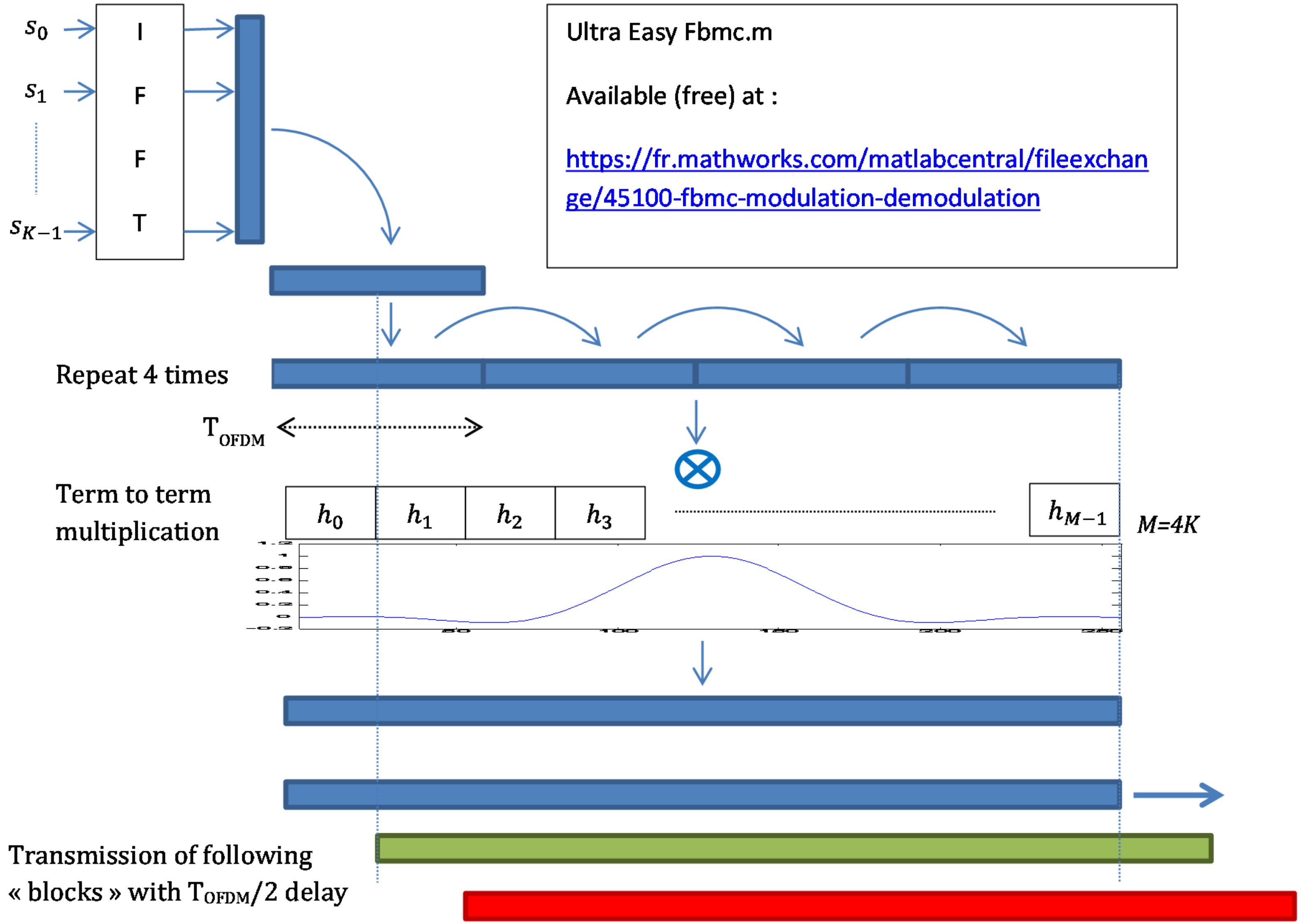
$$H_1 = 0.971960$$

$$H_2 = \frac{\sqrt{2}}{2}$$

$$H_3 = 0,235147$$

$$h_i = 1 - 2H_1 cos\left(\frac{i\pi}{2K}\right) + 2H_2 cos\left(\frac{i\pi}{K}\right) - 2H_3 cos\left(\frac{3i\pi}{2K}\right)$$

FBMC-OQAM (Filter Band MultiCarrier)

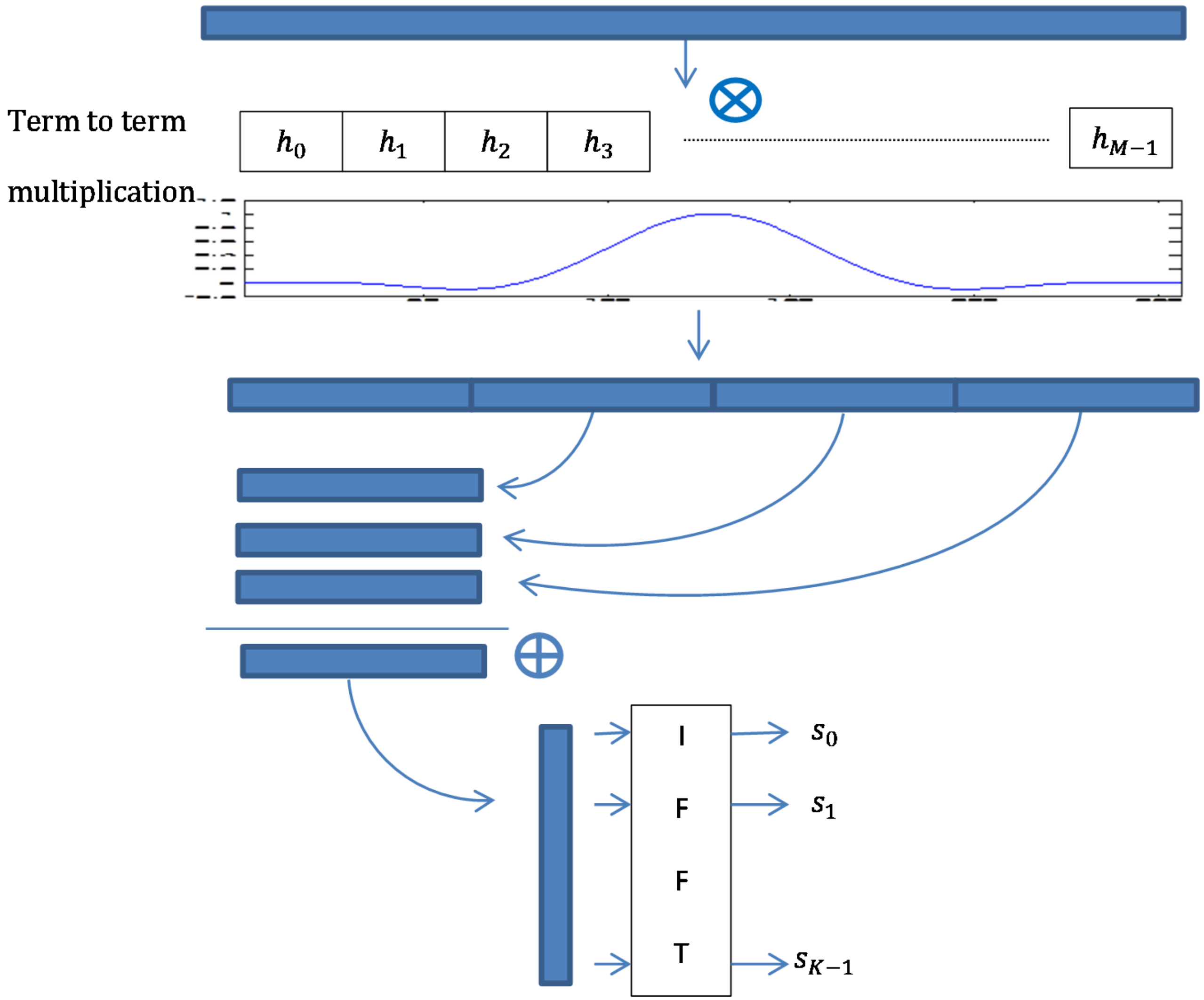


Ultra Easy Fbmc.m

Available (free) at :

https://fr.mathworks.com/matlabcentral/fileexchange/45100-fbmc-modulation-demodulation

FBMC-OQAM (Receiver)



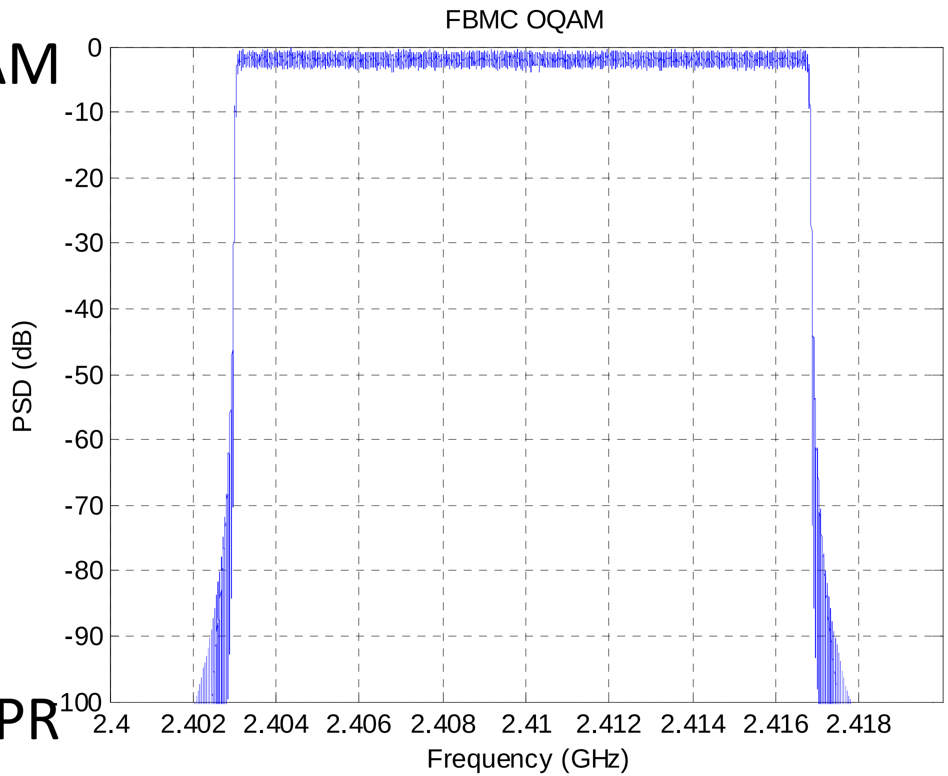
FBMC-OQAM

☺

- Reduced Side Lobes
- Spectral efficiency of M-QAM modulations
- No Cyclic Prefix

☹

- Complexity
- Loss of complex orthogonality
- Not well suited for MIMO
- Non constant Envelope, PAPR



FBMC–OQAM Interferences

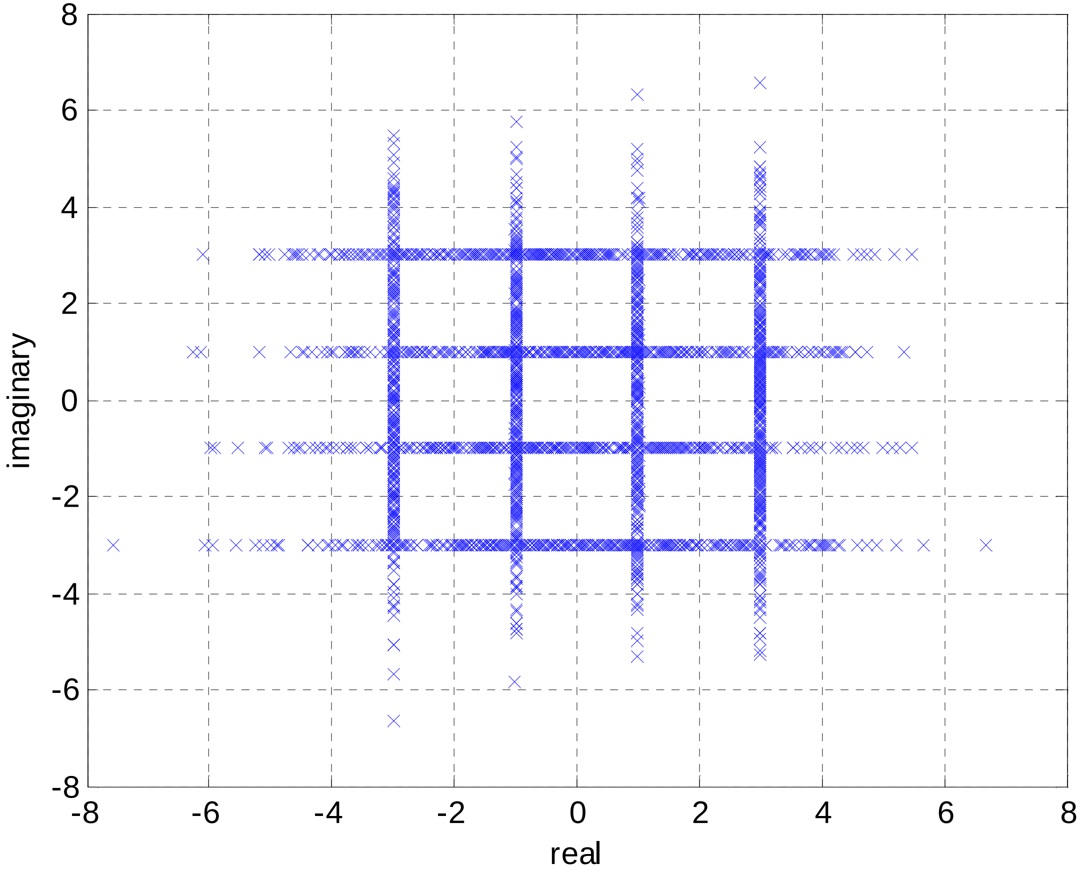
Interference Table,limited to adjacent sub-carriers

s.c./t	-T	-T/2	0	T/2	T
k-1	-0,1250	-0,2058j	0,2393	0,2058j	-0,1250
k	0,0002	0,5644	1	0,5644	0,0002
k+1	-0,1250	0,2058j	0,2393	-0,2058j	-0,1250

OQAM transmission table (equivalent to 2 interleaved PAM)

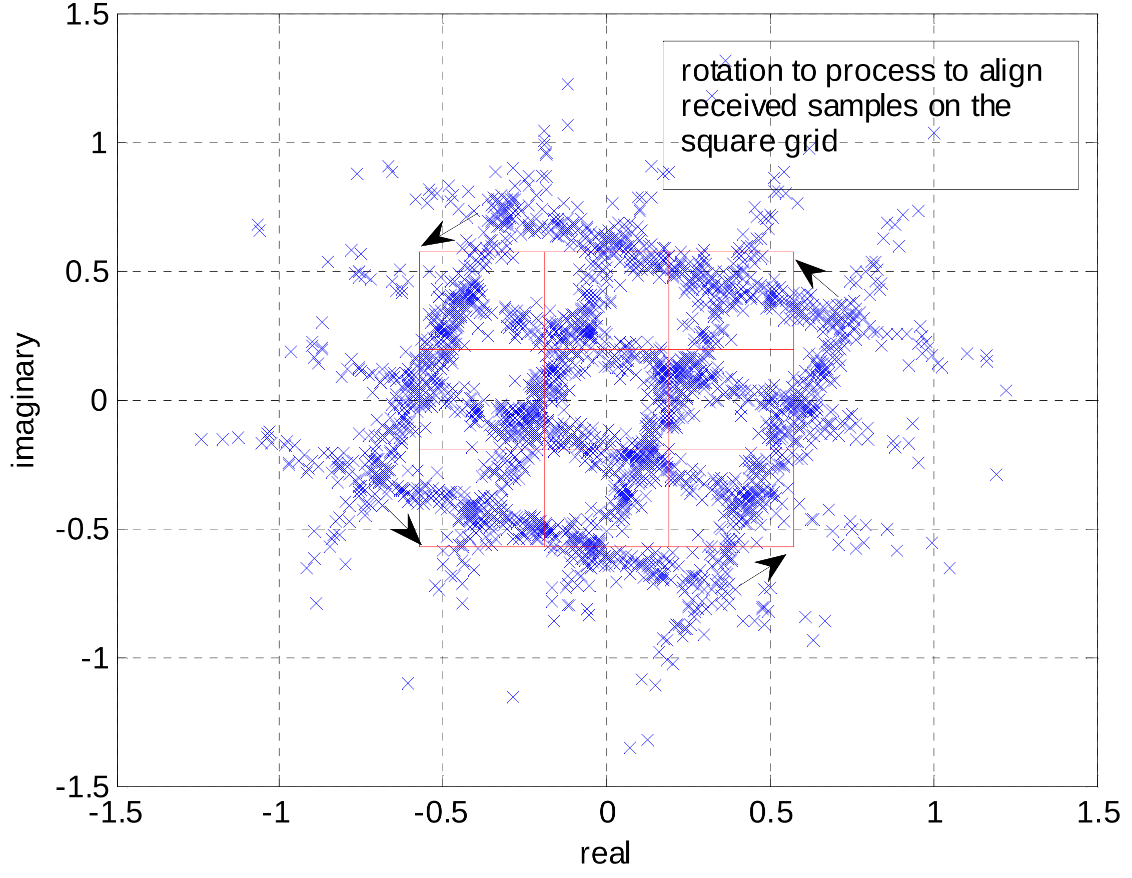
s.c./t	*-T*	*-T/2*	*0*	*T/2*	*T*
k-1	**Imaginary**	**Real**	**Imaginary**	**Real**	**Imaginary**
k	**Real**	**Imaginary**	**Real**	**Imaginary**	**Real**
k+1	**Imaginary**	**Real**	**Imaginary**	**Real**	**Imaginary**

Received 16-OQAM Constellation



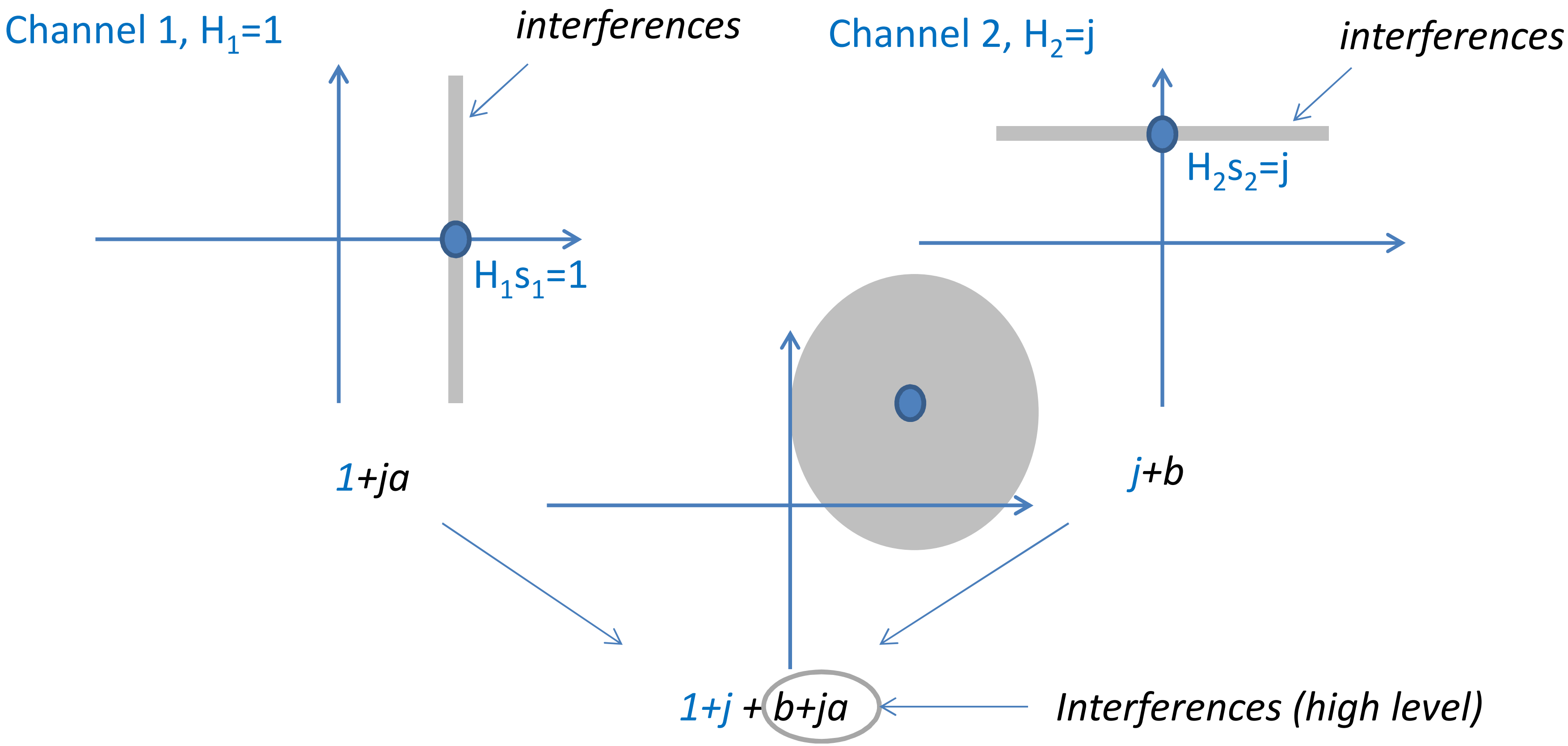
Received 16-OQAM Constellation

(with channel and noise)



MIMO Problem

Ultra simple case



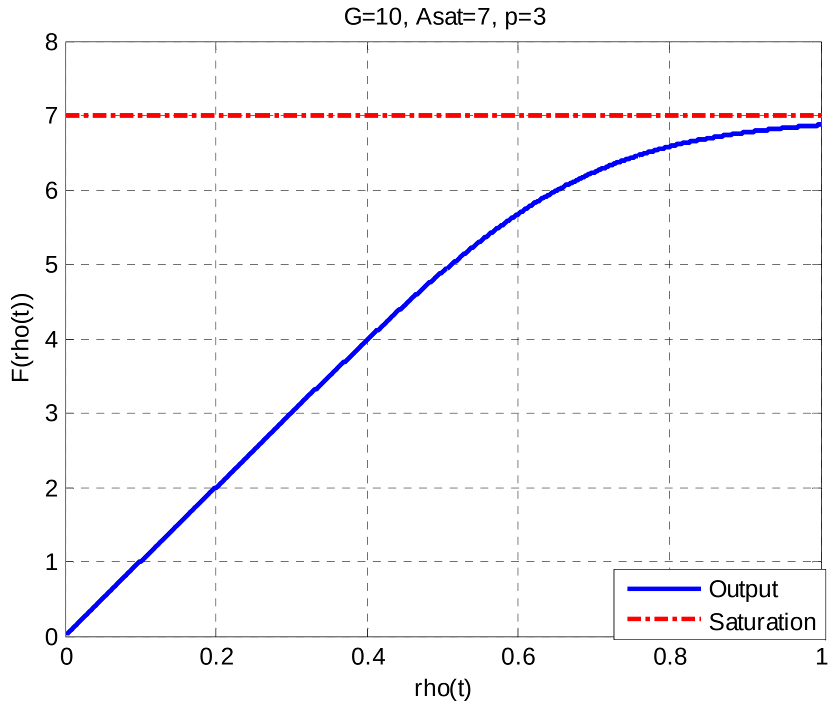
High Power Amplifier (HPA) and PAPR

(Peak to Average Power Ratio)

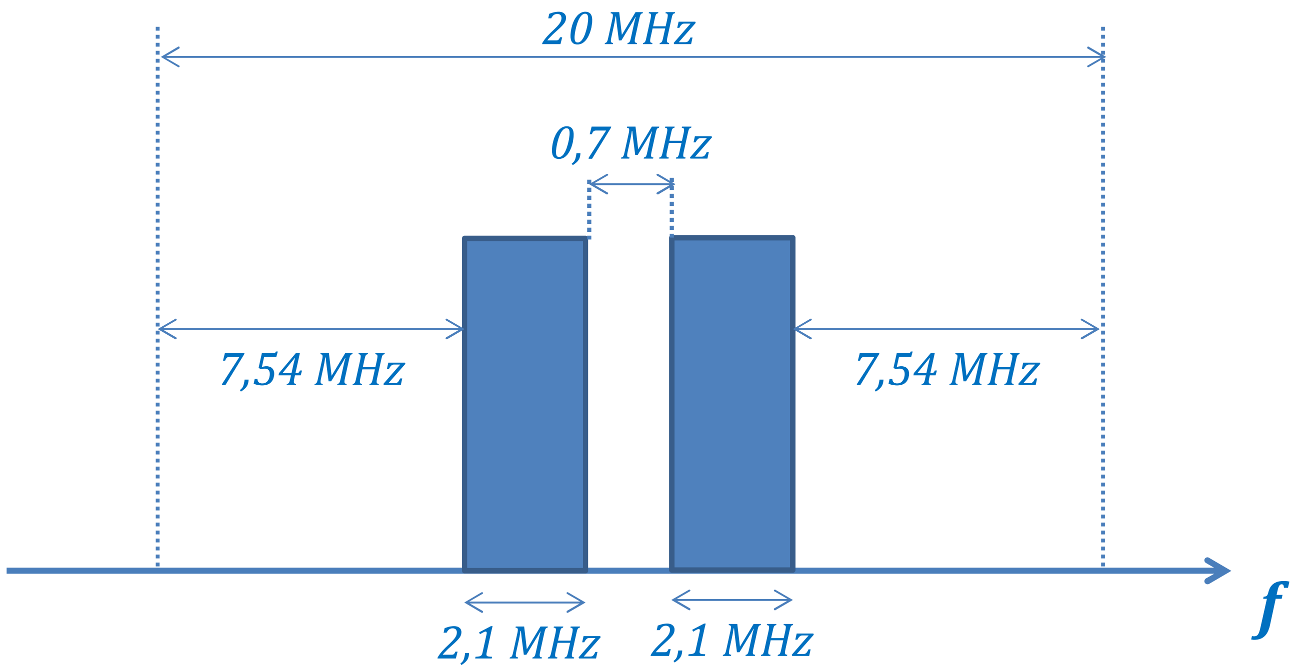
Input signal $x(t) = \rho(t)e^{j\omega t}$ → **HPA** → $y(t) = F\big(\rho(t)\big)e^{j\varphi(t)}$ Output signal

$$F(\rho(t)) = \frac{G\rho(t)}{\left(1 + \left|\frac{G\rho(t)}{A_{sat}}\right|^{2p}\right)^{\frac{1}{2p}}}$$

Modified Rapp Model

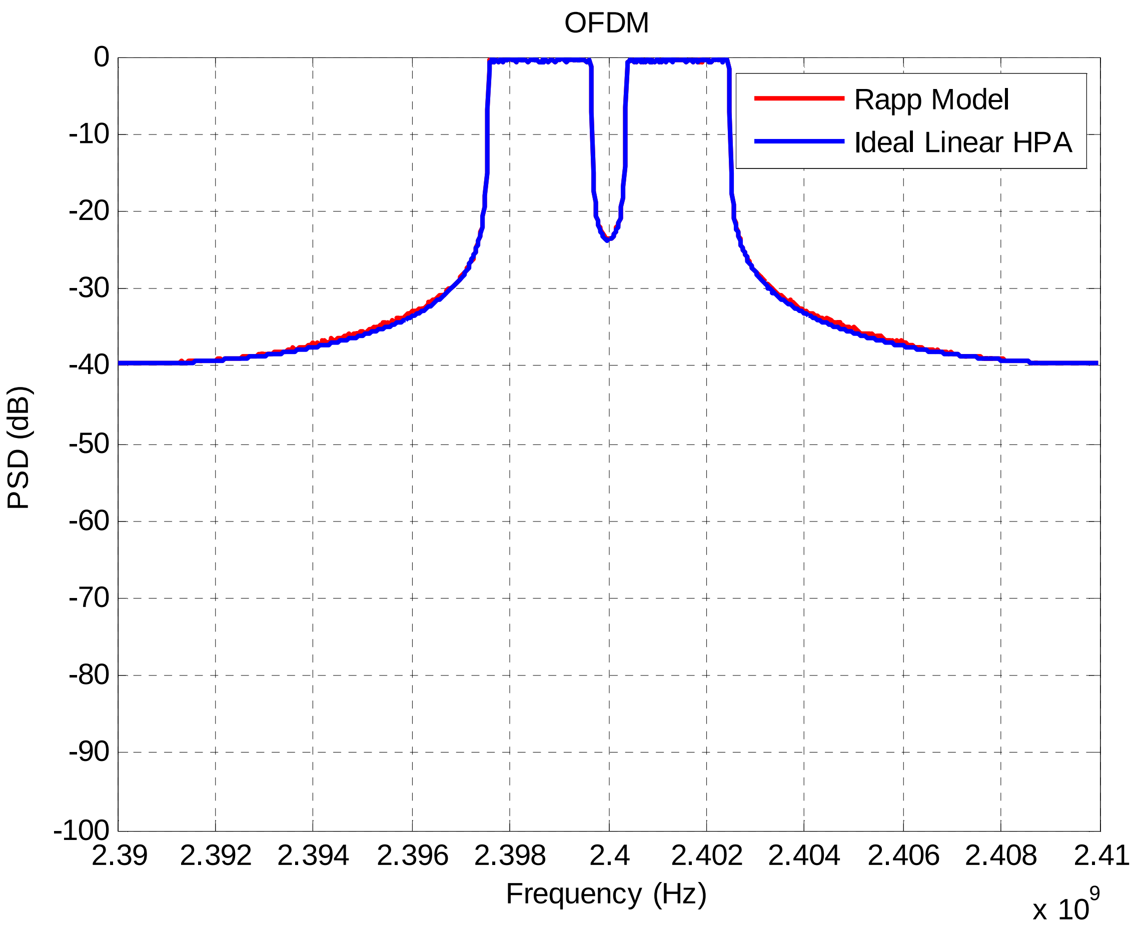


Out Of Band (OOB) Transmissions

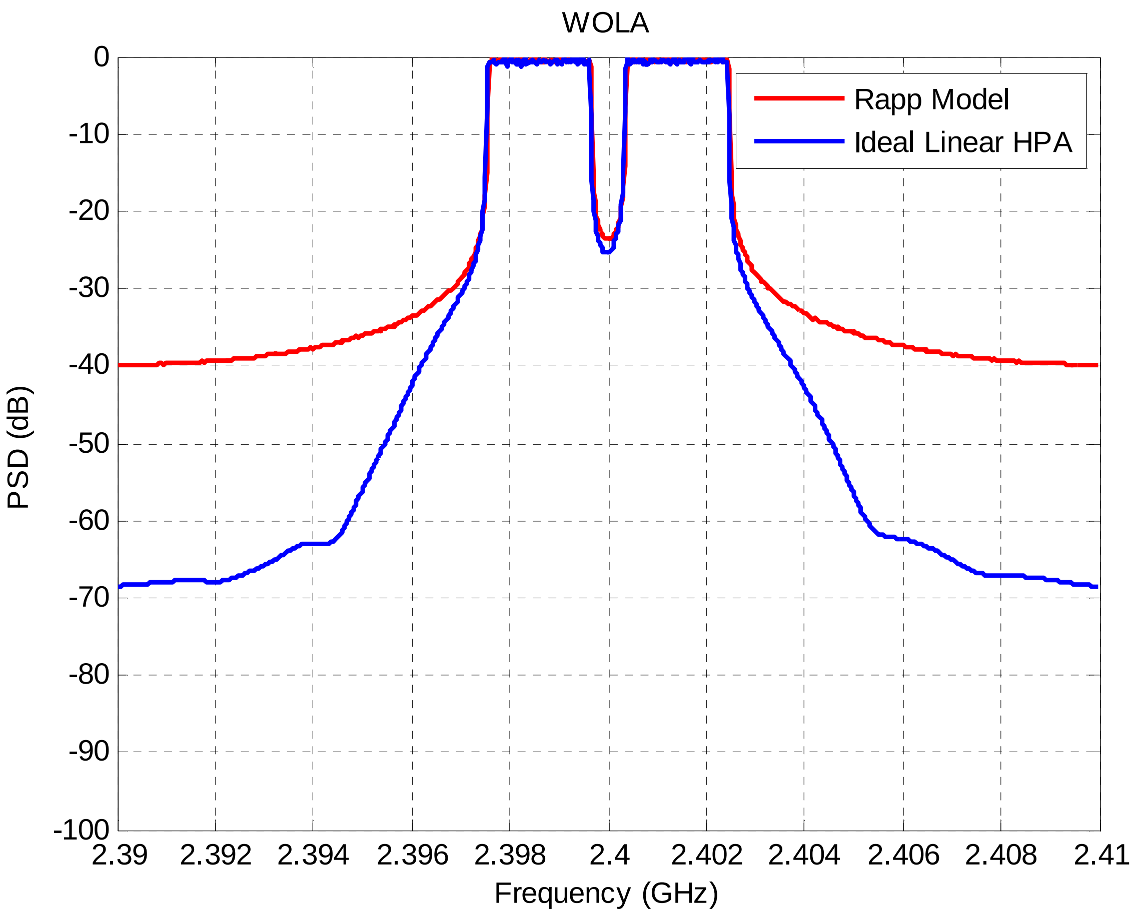


H. Shaiek, R. Zayani, Y. Medjahdi, D. Roviras. "**Analytical analysis of SER for beyond 5G post-OFDM Waveforms in presence of High Power Amplifiers**", *IEEE Access*, pp. 1-13, 2019, (doi:10.1109/ACCESS.2019.2900977)

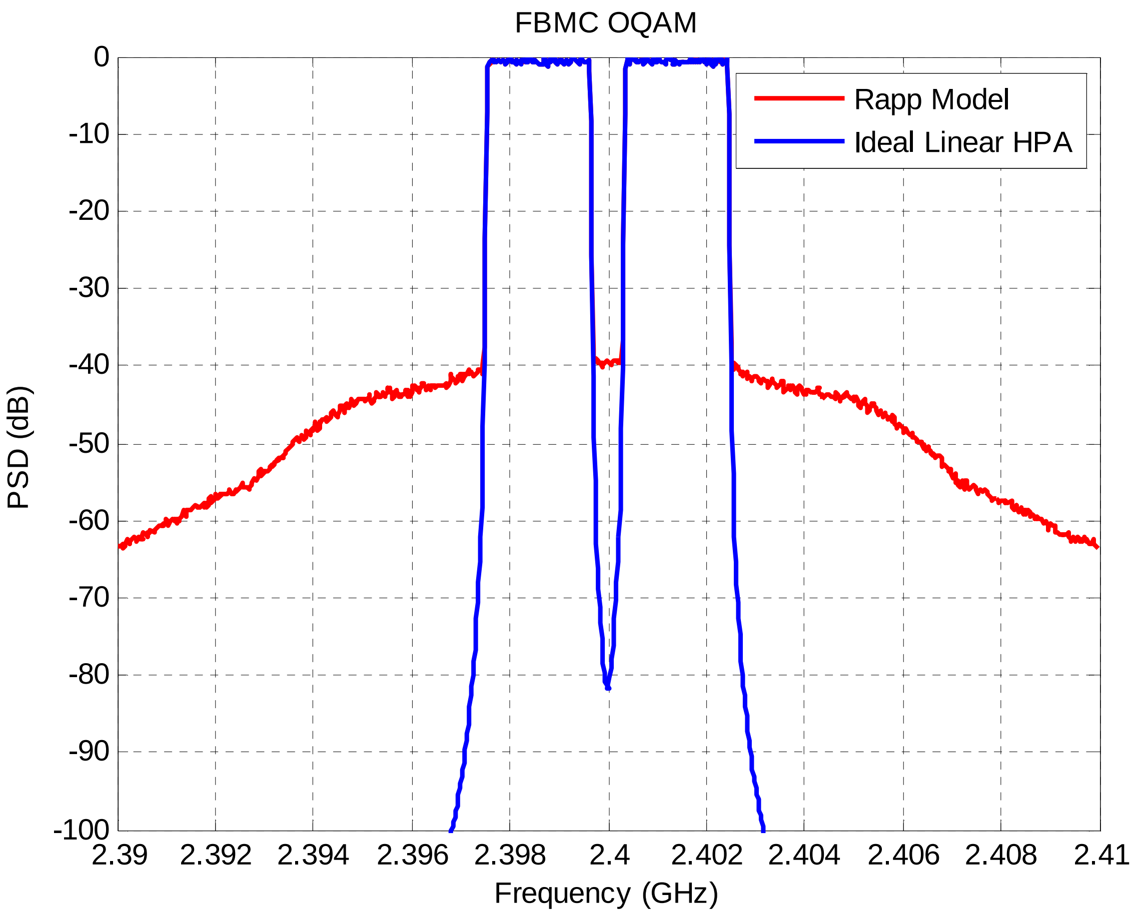
OOB CP-OFDM and HPA



OOB WOLA and HPA



OOB FBMC-OQAM and HPA

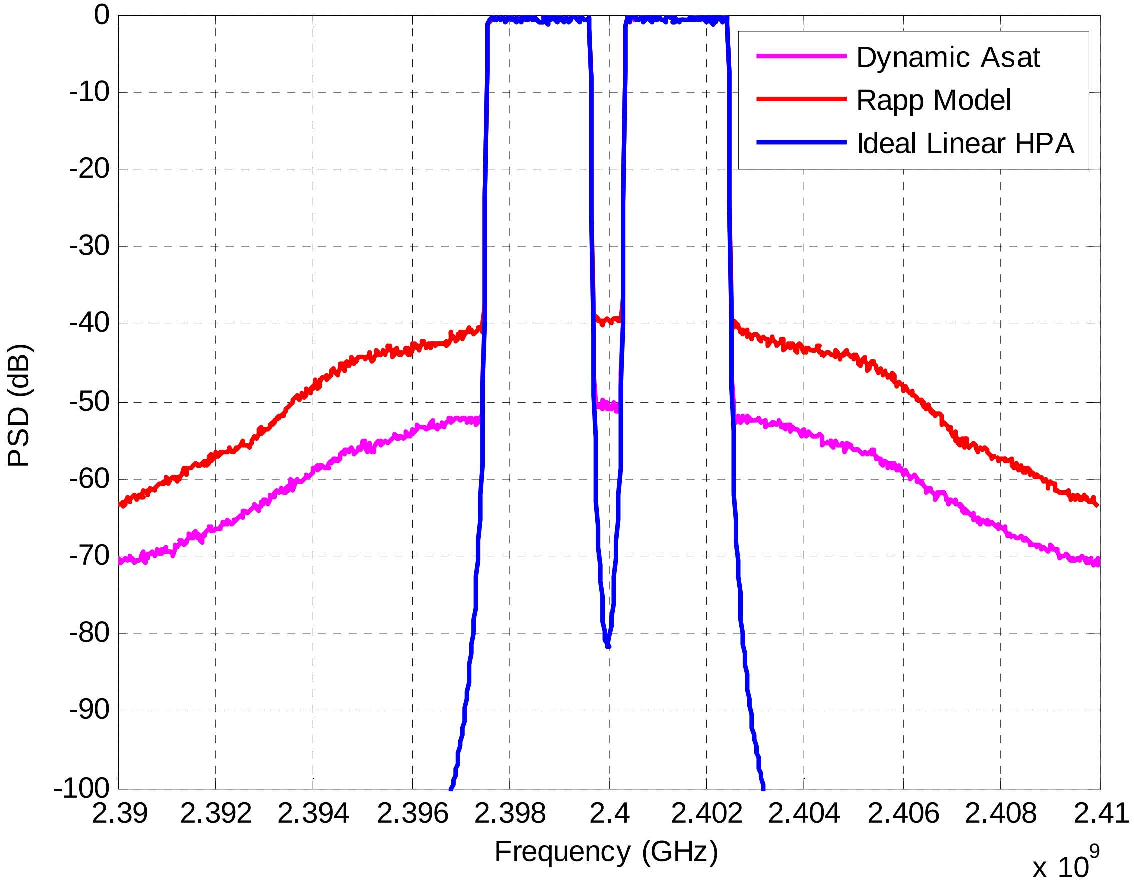


HPA with a dynamic saturation level ?

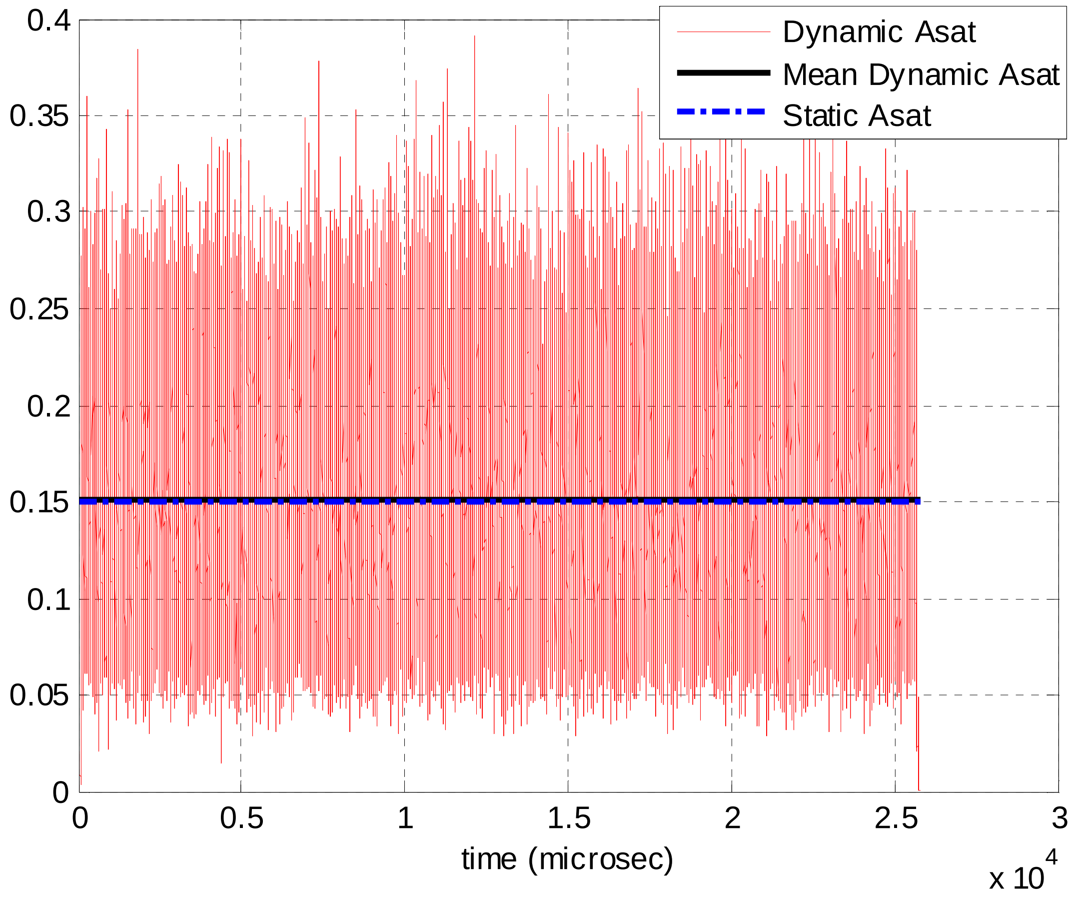
$$F(\rho(t)) = \frac{G\rho(t)}{\left(1 + \left|\frac{G\rho(t)}{A(t)_{sat}}\right|^{2p}\right)^{\frac{1}{2p}}}$$

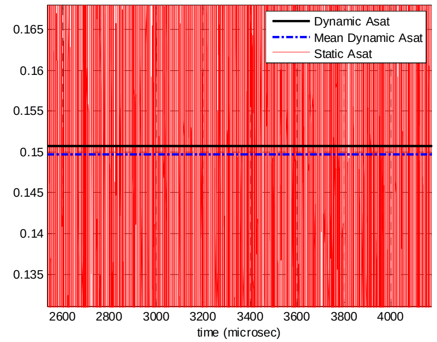
$$A_{sat}(t) = f(\{x(t-p), \dots, x(t), \dots, x(t+p)\})$$

OOB FBMC-OQAM and dynamic saturation level

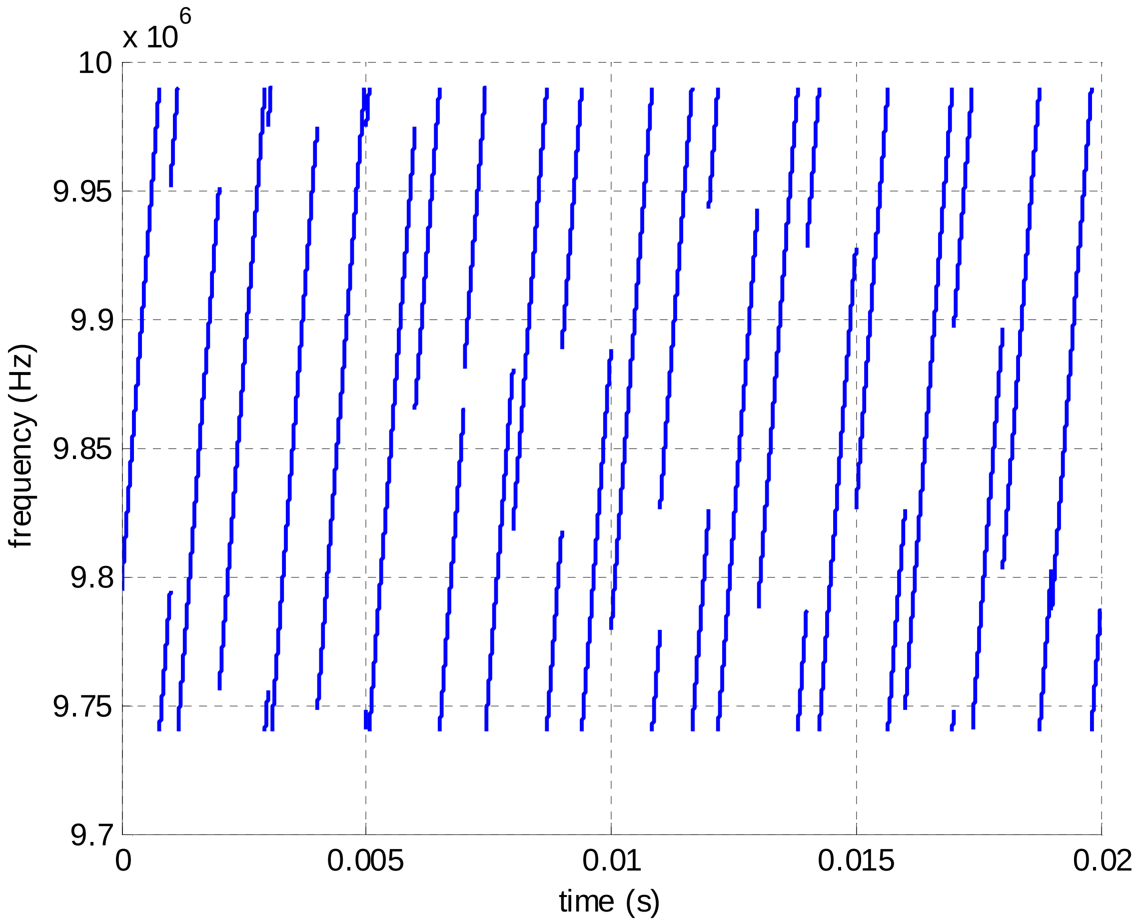


Dynamic saturation level evolution

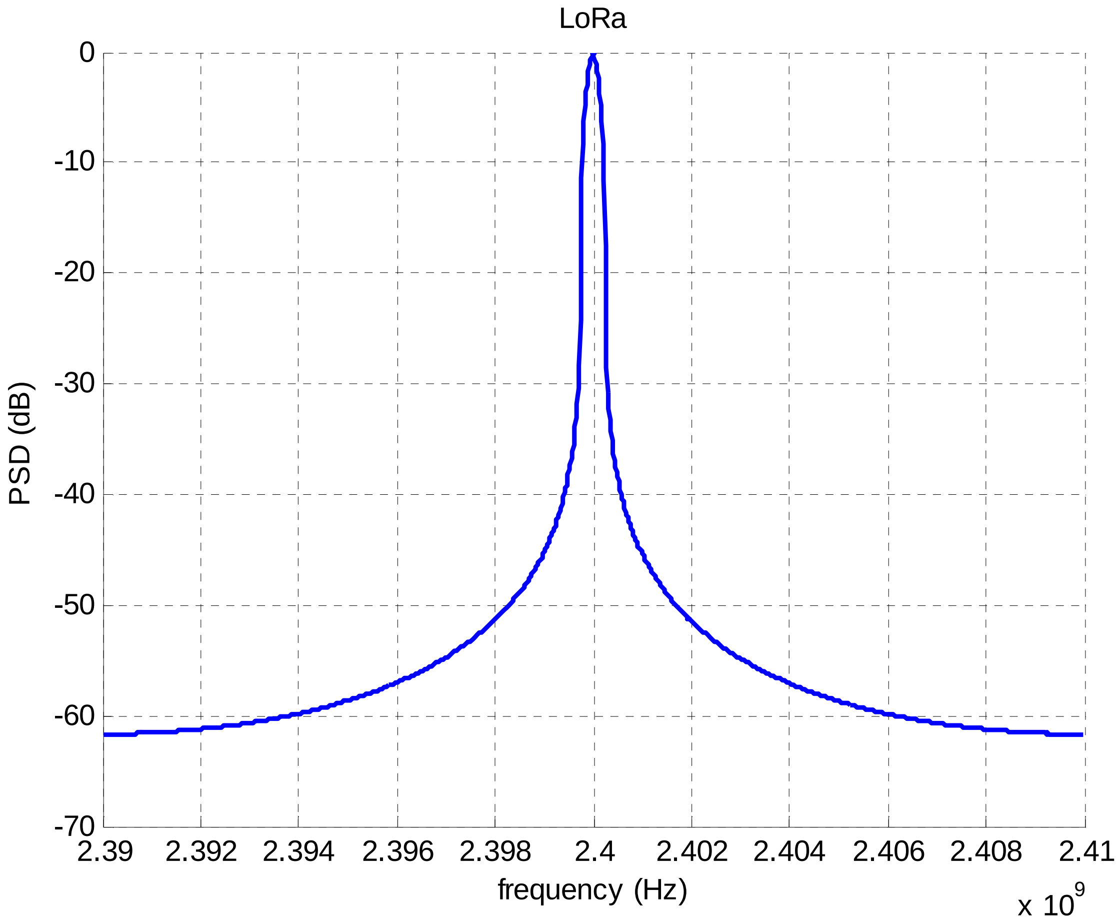




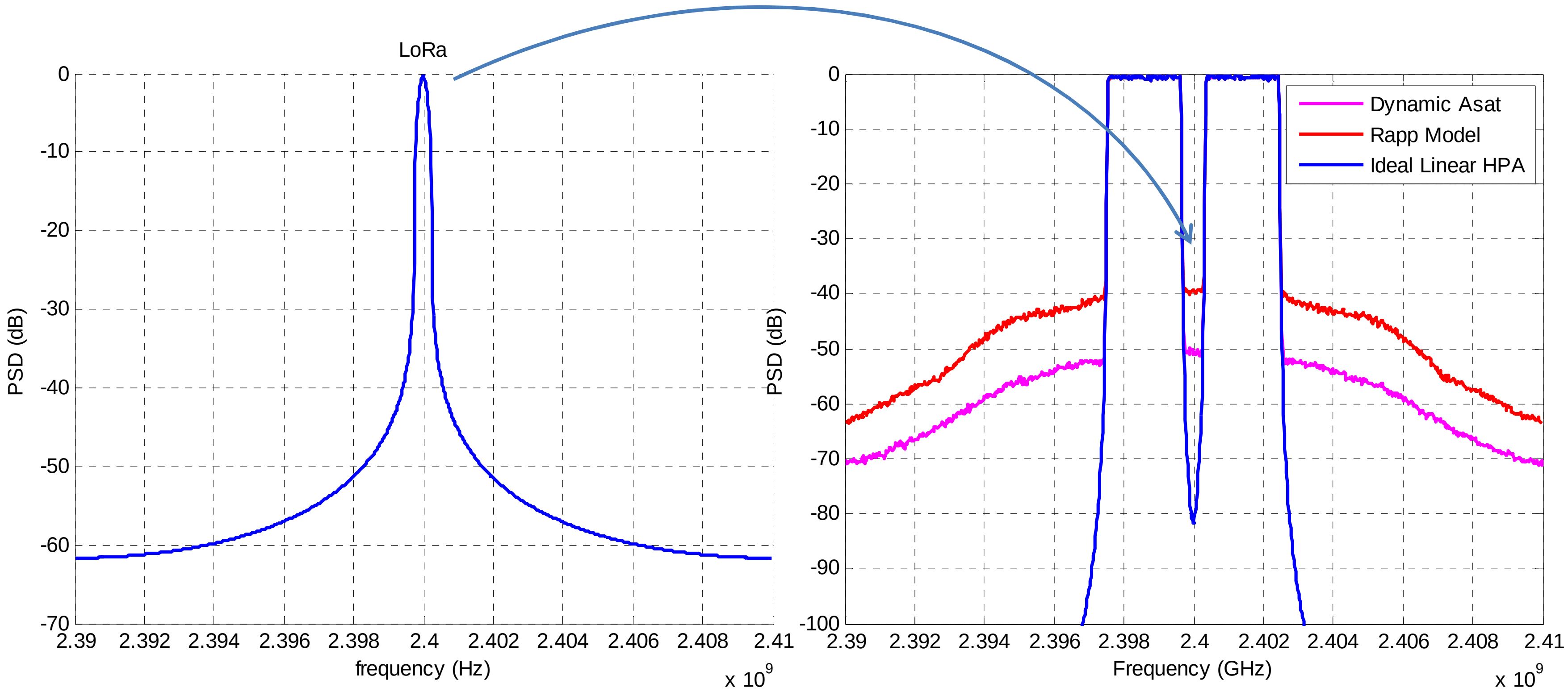
Lora Chirp Spread Spectrum



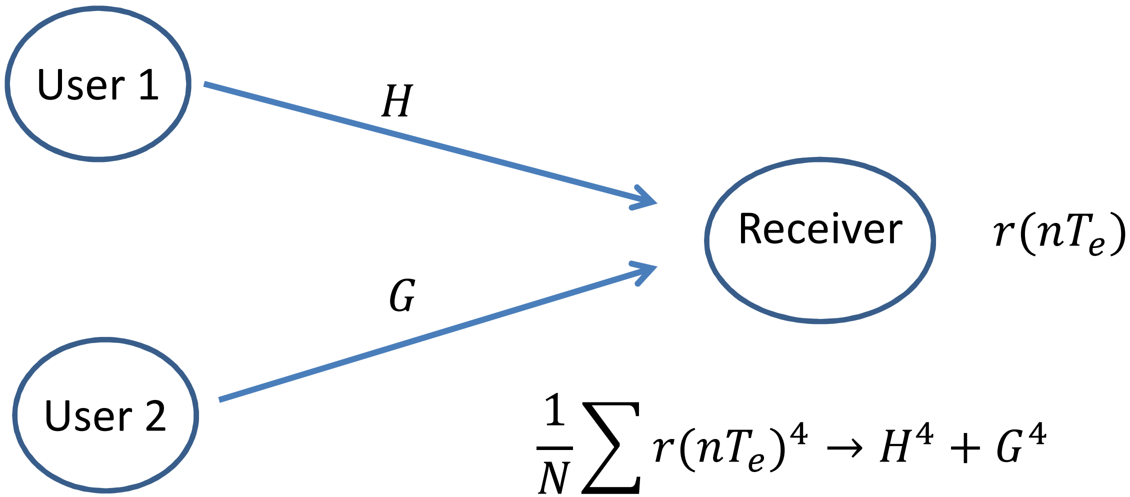
Lora Chirp Spread Spectrum



Lora Chirp Spread Spectrum



Blind Interferences cancellation



$$\frac{1}{N}\sum_n r(nT_e)^4 \rightarrow H^4 + G^4$$

$$\frac{1}{N}\sum_n r(nT_e)^8 \rightarrow H^8 + 70H^4G^4 + G^8$$

$$X = H^4, Y = G^4 \longrightarrow \begin{cases} X + Y = a \\ X^2 + 70XY + Y^2 = b \end{cases}$$

Stanley Smith et al., "A moment-based estimation strategy for underdetermined single-sensor blind source separation," IEEE Signal Processing Letters, pp 1-5, April 2019.

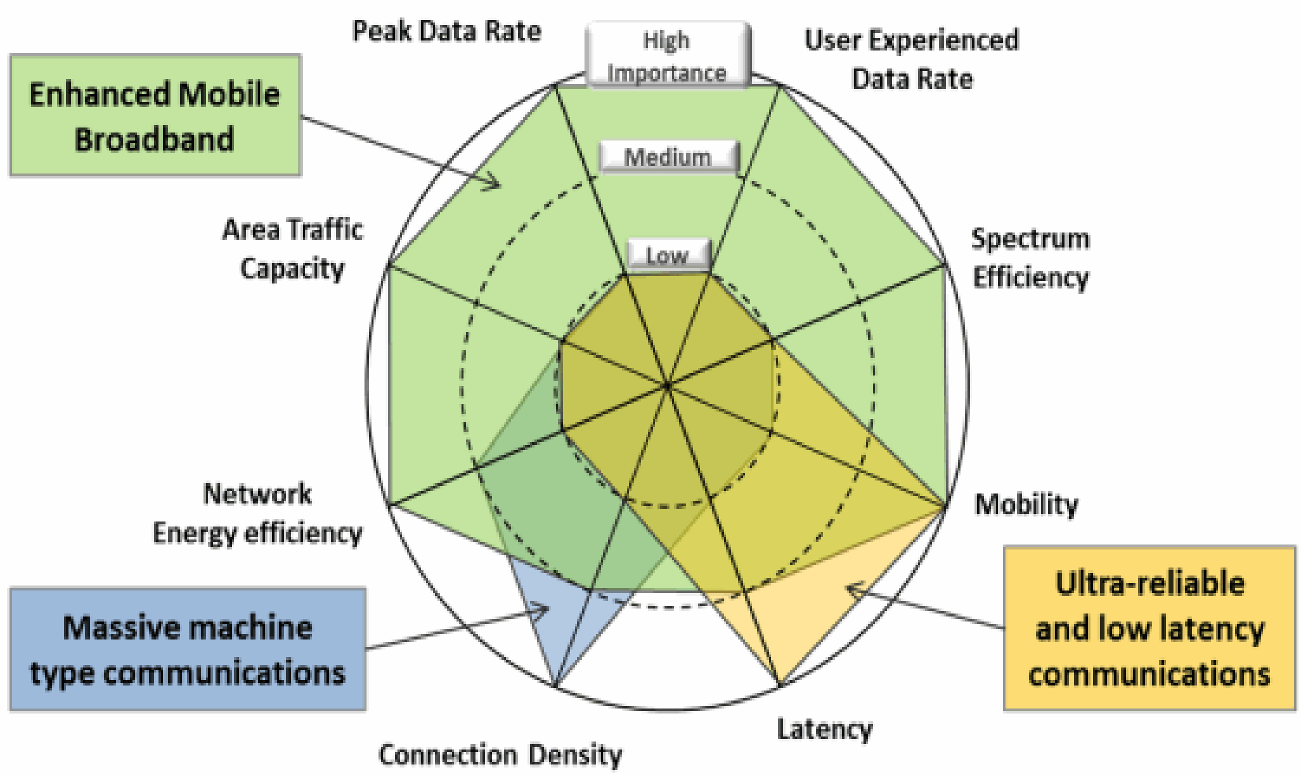
Conclusion

- Universal waveform for all 5G services ?
- Interference Mitigation for Massive IoT Deployments

Dead Line : December 1st

https://www.hindawi.com/journals/wcmc/si/375608/cfp/

Thank you for your attention



[Source: ITU-R M.2083-0 IMT Vision]