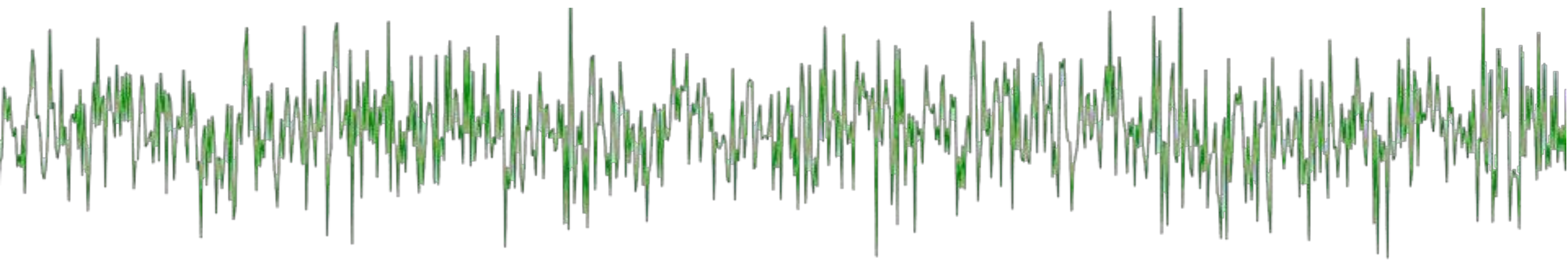
NOISE RADAR TECHNOLOGY:

WAVEFORMS DESIGN



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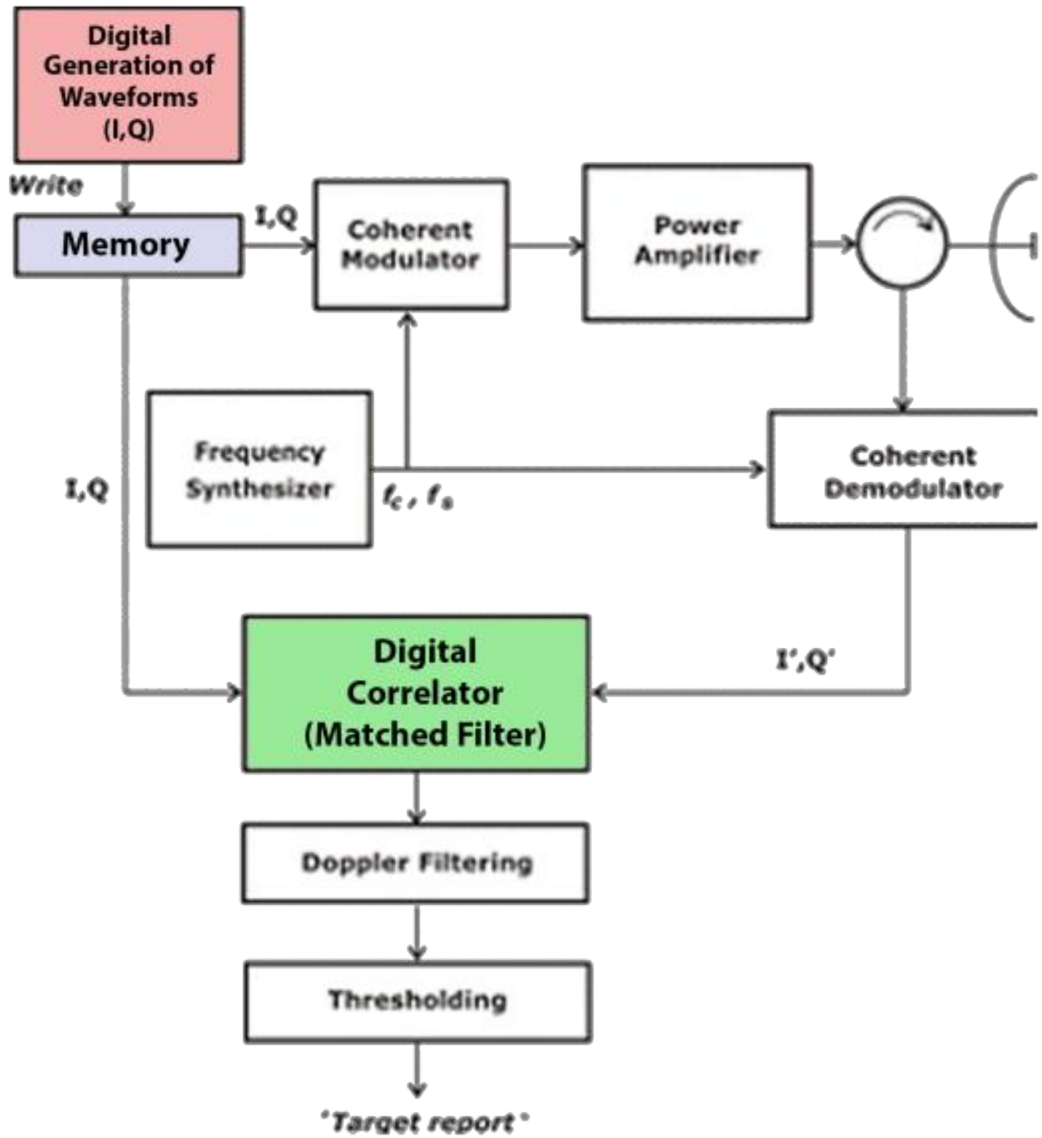
''Tor Vergata University'' - Rome

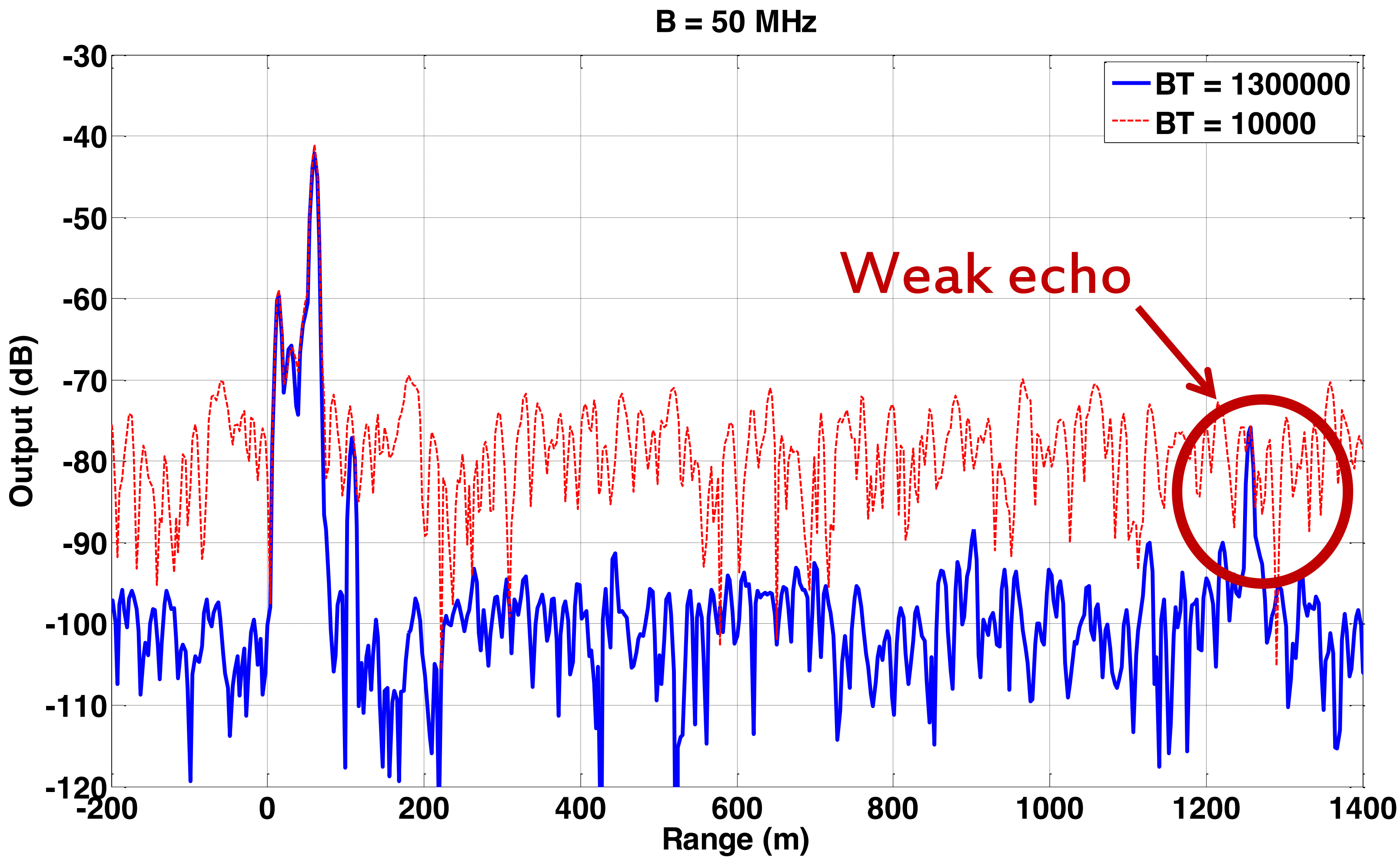
July 7-11, 2014 Bressanone (BZ)

Coherent Noise Radar Architecture

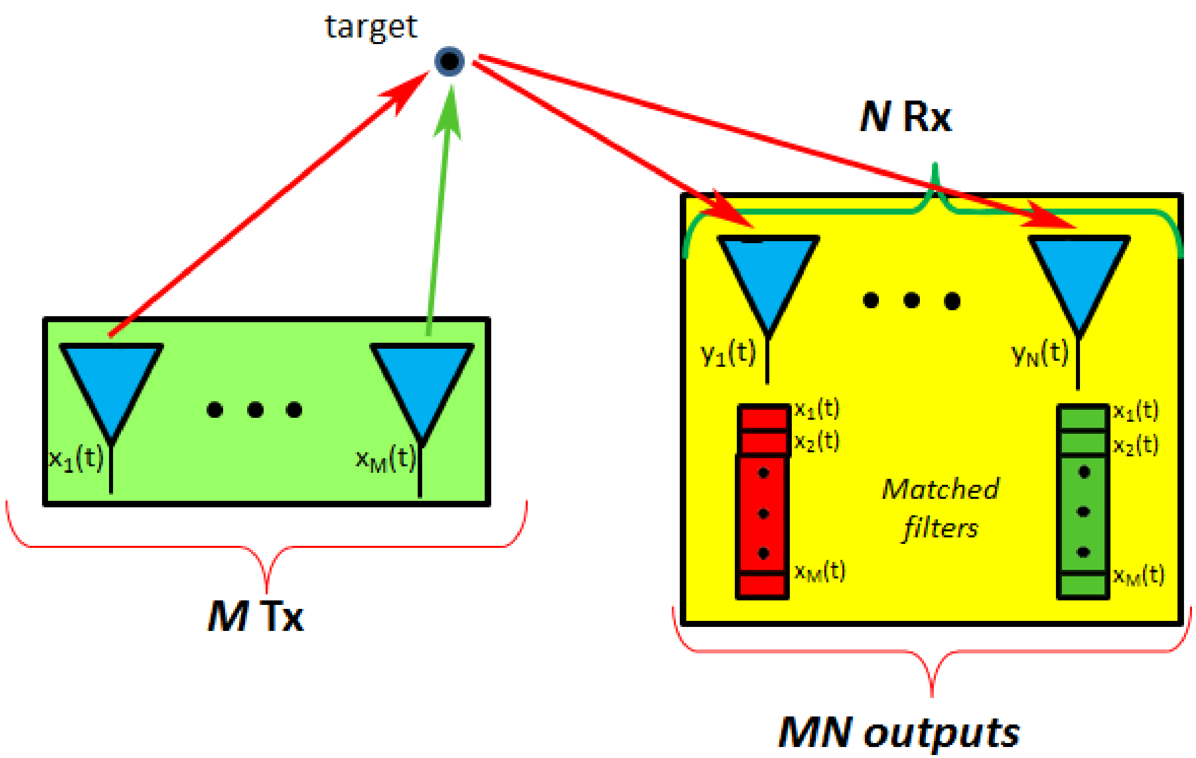


COHERENT NOISE RADAR ARCHITECTURE

An example of the output of the matched filter:
the masking effect



MIMO RADAR



MIMO radar: transmits M different signals which are processed at the receiver side by N different matched filters.

Requirements: Orthogonal waveforms

THE GOALS

We want to generate radar signals that:

- Avoid the **masking effect**
- Are **orthogonal** to each other (marine environment)

…and…

- have **LPID** properties (military environment)

LPI & LPID PROPERTIES

‘To see and Not Be Seen’

«The term **LPI** is that property of a radar that, because of its **low power**, wide bandwidth, frequency variability, or other design ottributes, makes it difficult for it to be detected by means of passive intercept receiver»

«The term **LPID** is a radar with a waveform that makes it difficult for an intercept receiver to correctly identify the **parameters** and radar type»

Generation of Digital Waveforms

- Deterministic
- Purely Noisy
- Mixed

Generation of Digital Waveforms

Deterministic

Deterministic signals

- **Linear** FM signals (i.e. Chirp)
- **Non Linear** FM signals (i.e. Millett)
- **OFDM** signal

- **Hybrid Non Linear FM** signal

Hybrid Non Linear FM signal

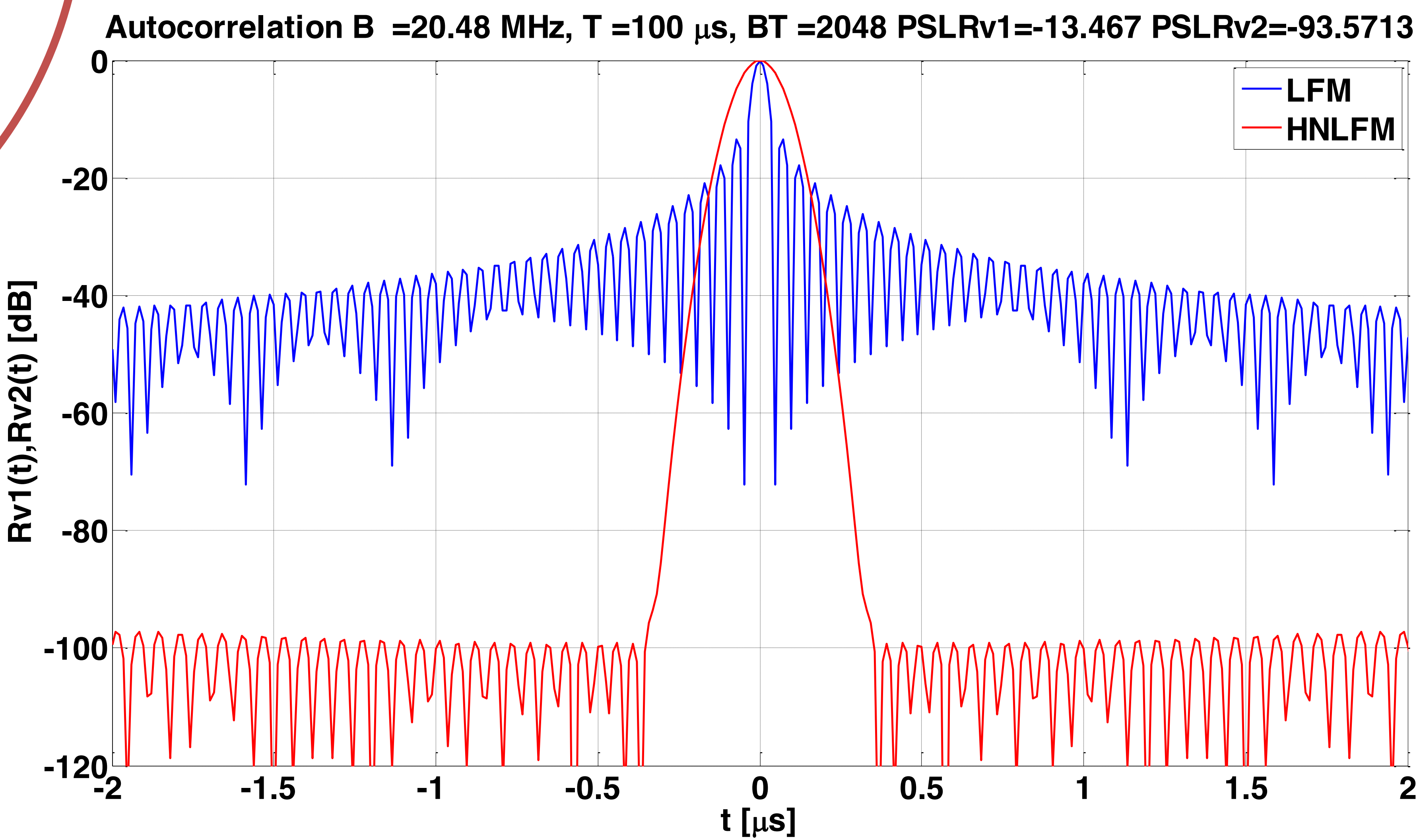
Hybrid Non Linear FM signal [*,**] exploits the principle of stationary phase in order to achieve very low range sidelobes (-100 dB @ BT=4096) and moderate Doppler tolerance.

$$\phi'(t) = \pi B \left\{ \underbrace{\alpha \frac{1}{tg(\gamma)} tg\left(\frac{2\gamma B}{T}\right)}_{\text{Non Linear term}} + \underbrace{(1-\alpha)\frac{2t}{T}}_{\text{Linear term}} \right\}$$

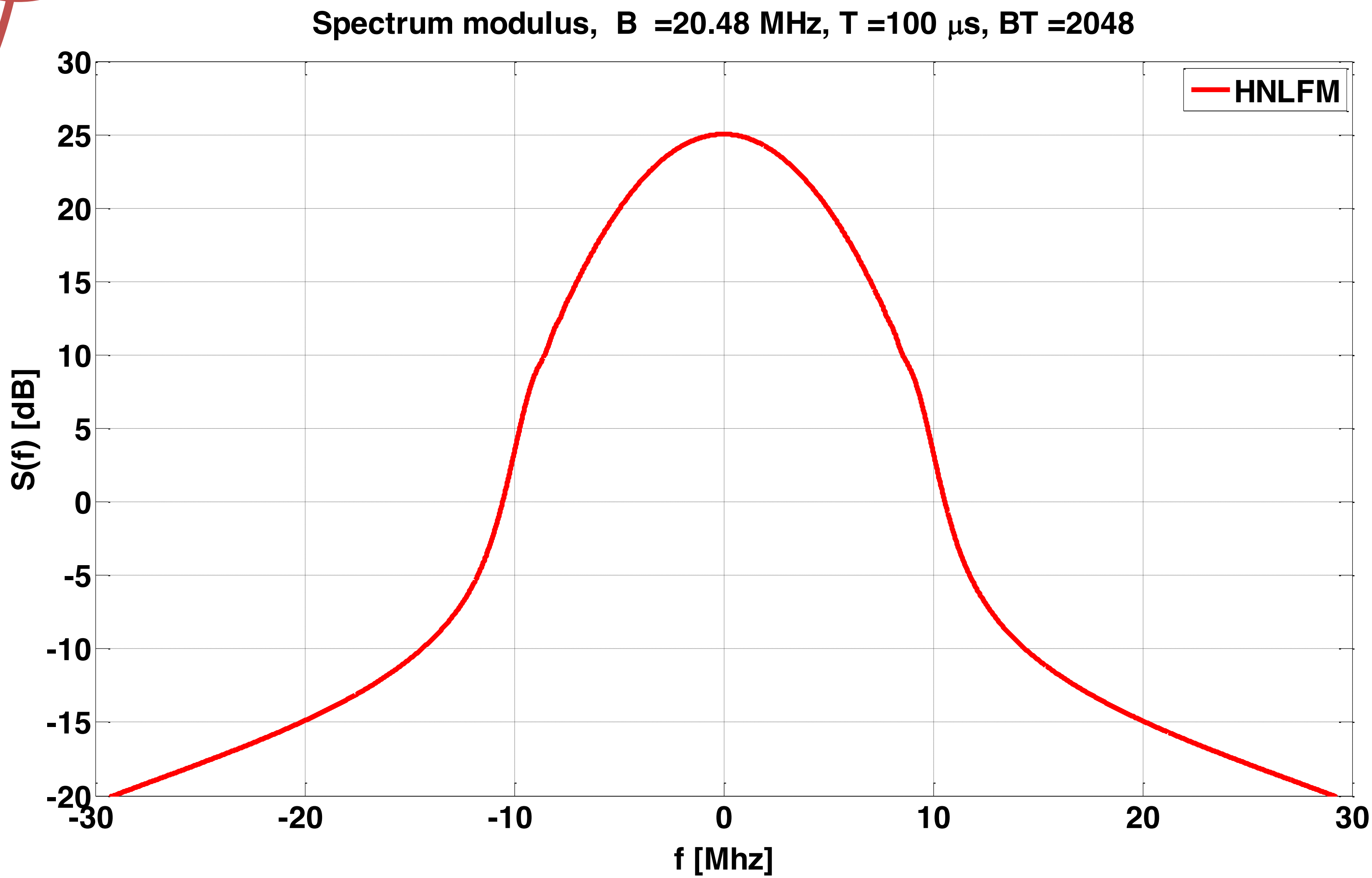
Non Linear term **Linear term**

- * Zhiqiang, Peikang, Weining *"Matched NLFM Pulse Compression Method with Ultra-low Sidelobes"*
- ** T. Collins, P.Atkins *'Nonlinear frequency modulation chirps for active sonar"*

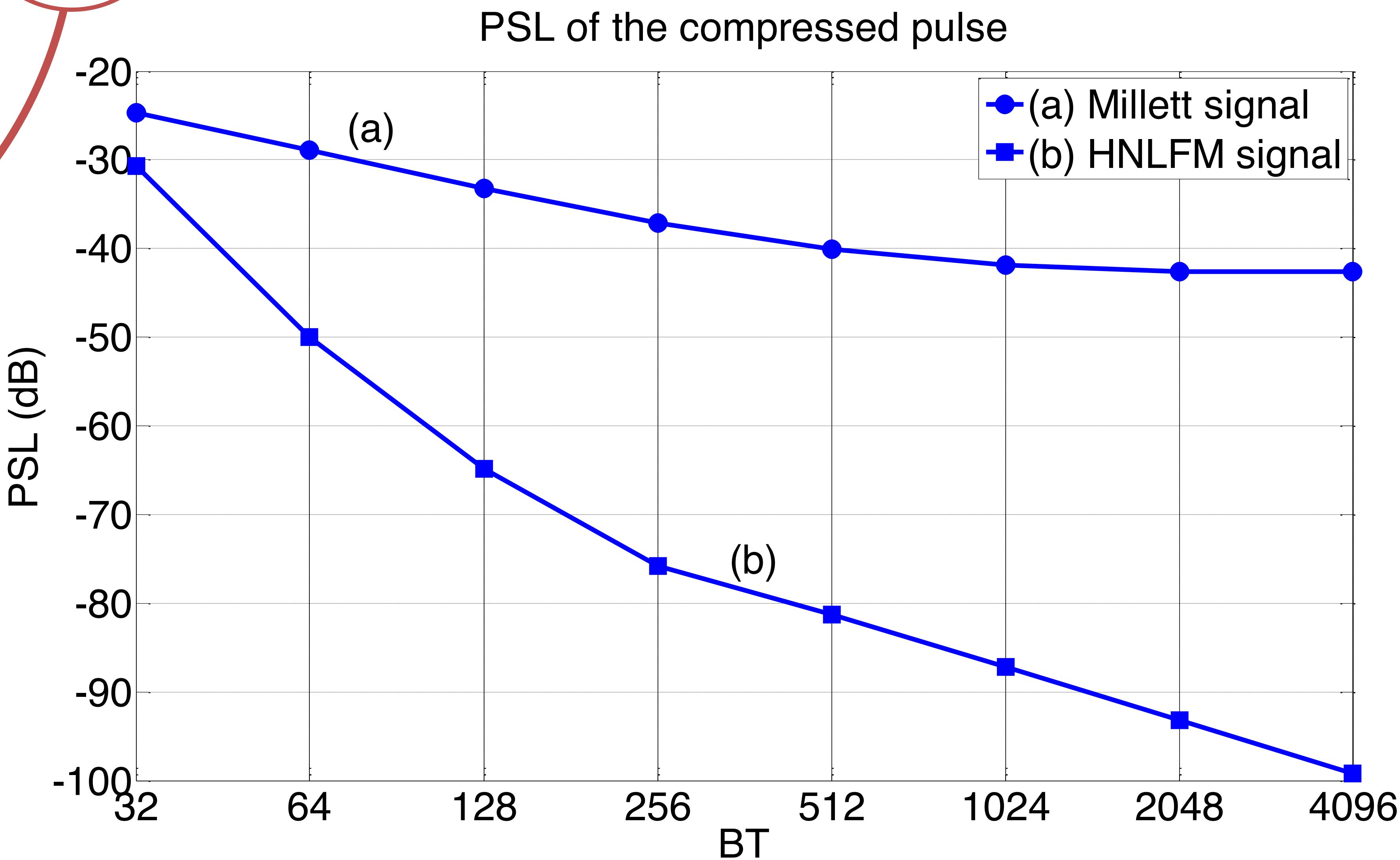
Deterministic signals



Deterministic signals



Deterministic signals



Deterministic signals

Advantages

Good PSLR

- Avoid masking effect -

Limited bandwidth

Disadvantages

Predictability

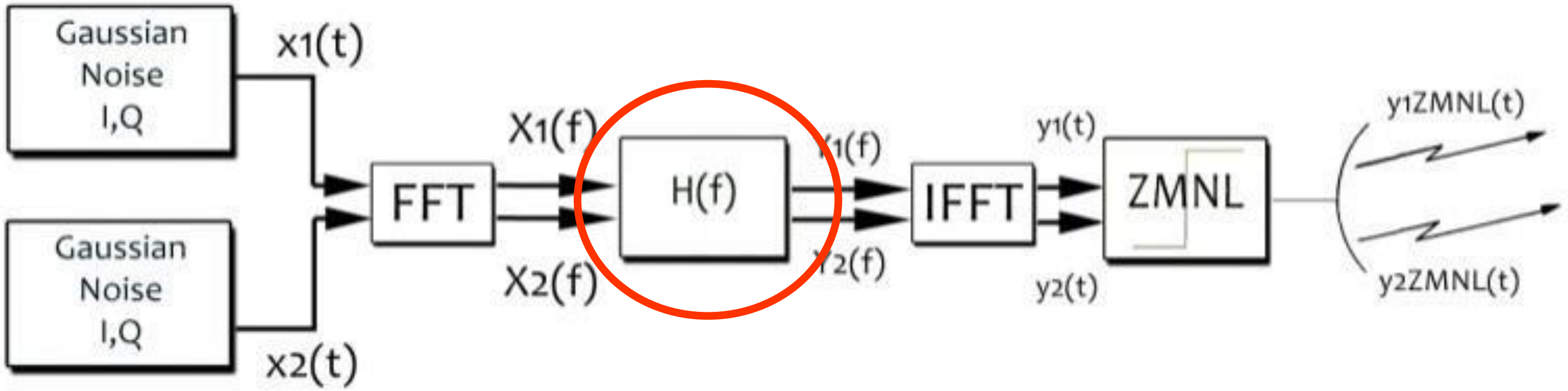
- Poor LPID properties –

Only 2 orthogonal signals

Generation of Digital Waveforms

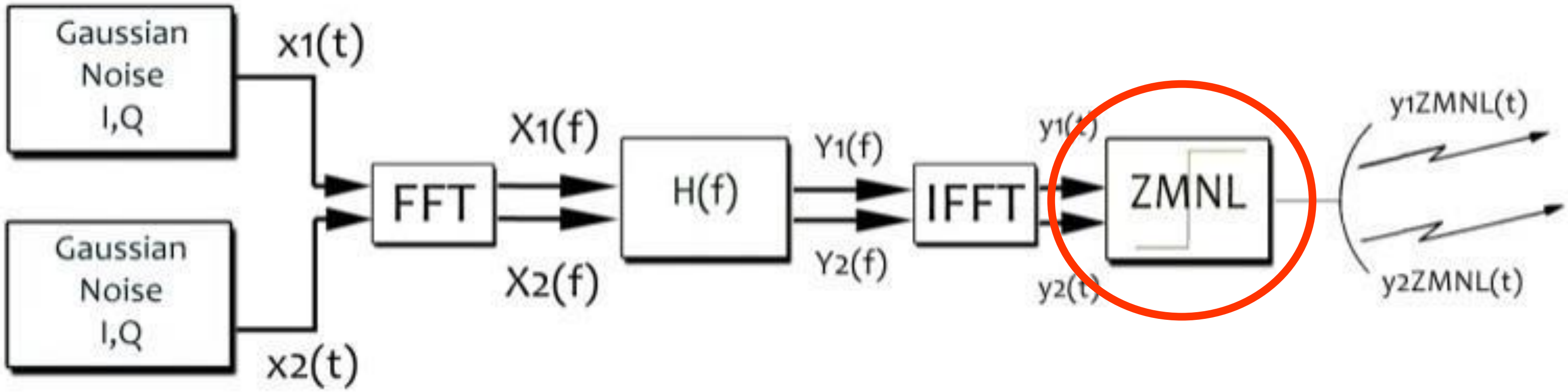
Purely Noisy

Purely Noisy signals



$H(f)$ is a **Blackman-Nuttall** window whose inverse Fourier transform gives very low sidelobes.

Purely Noisy signals



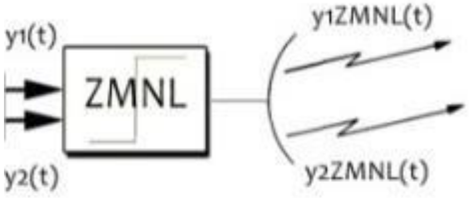
$$MEPPR = \frac{\frac{1}{T}\int_0^T |s(t)|^2 dt}{\max\{|s(t)|^2\}}$$

Mean Envelope to Peak Power Ratio

To maximize the trasmitter efficency, **MEPPR** has to be close to the unity

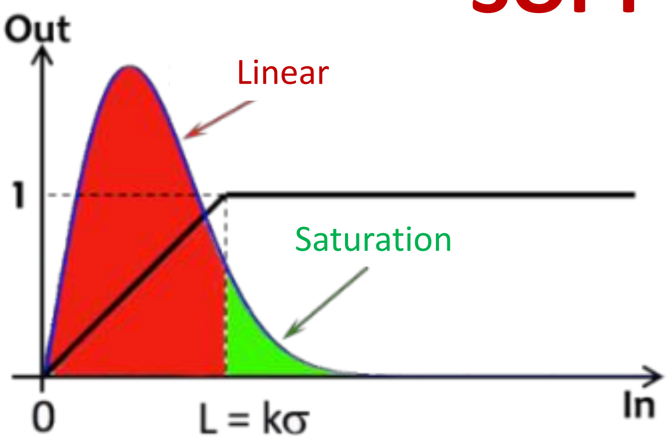
Purely Noisy signals

Zero-Memory-Non-Linearity transformation



The amplitude limiter may be:

SOFT



HARD

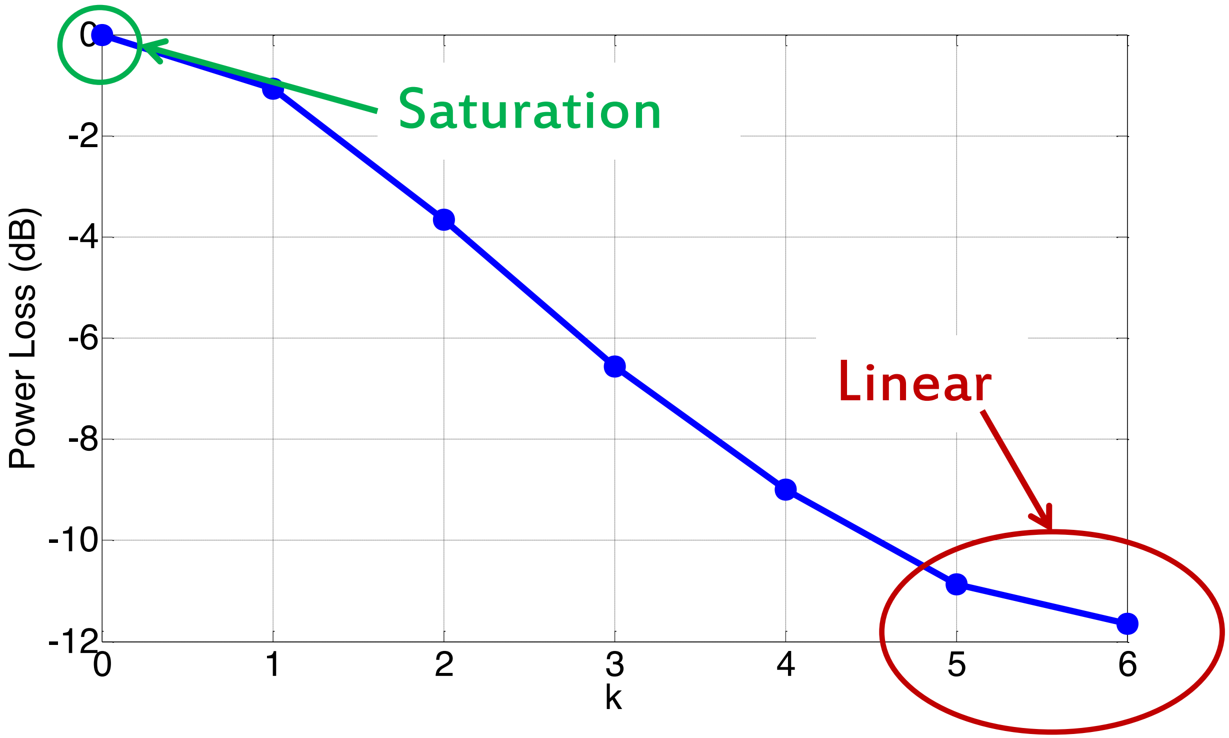
$$I' = \frac{I}{\sqrt{I^2 + Q^2}}$$

$$Q' = \frac{Q}{I^2 + Q^2}$$

Purely Noisy signals

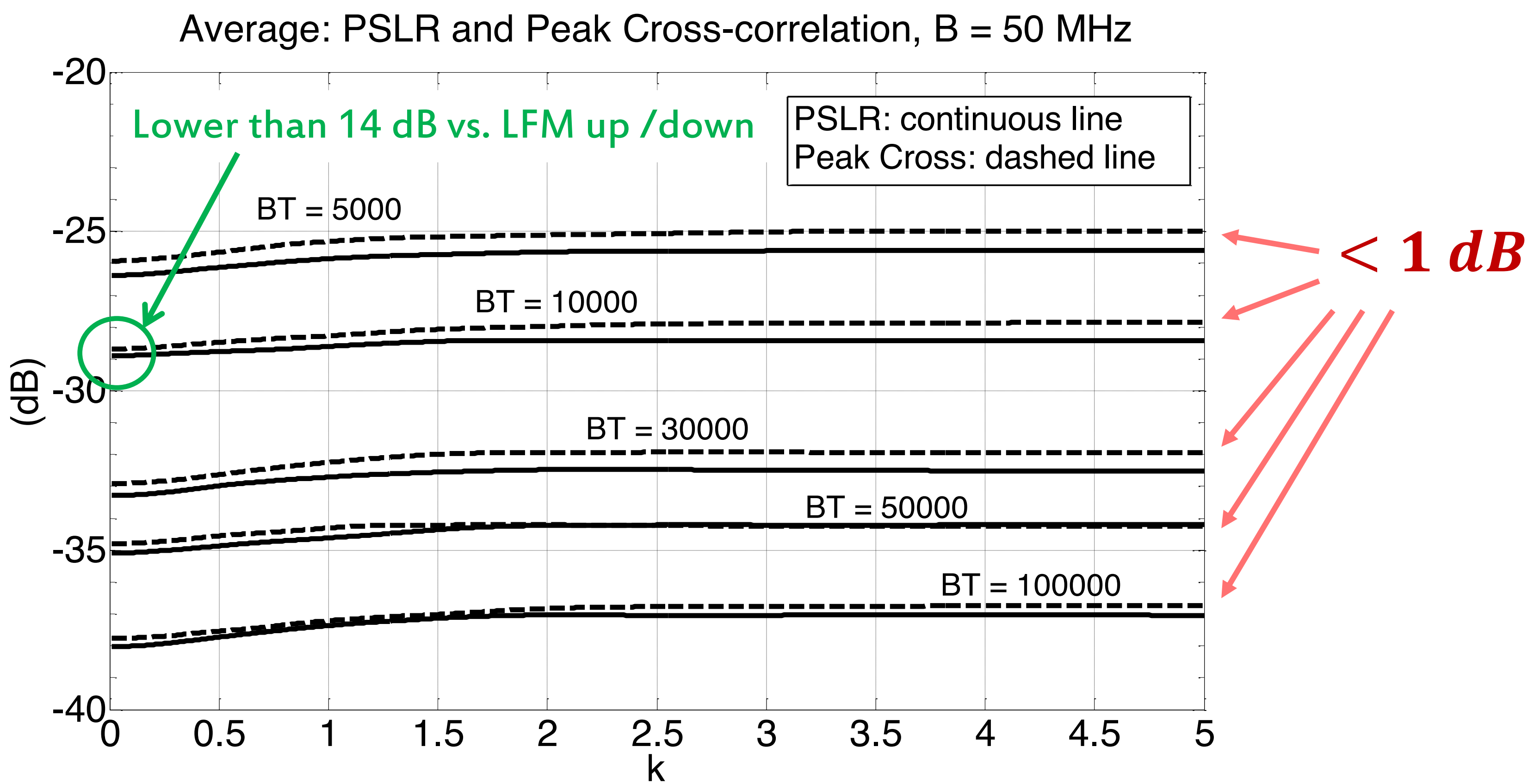
Losses:

In many applications the minimization of the tx power loss may be an important requirement.



$$Loss(k\sigma) = 10\log_{10}\{MEPPR(k\sigma)\}\ dB$$

Choice of the limiter threshold [k]



Given BT, variations of k ($k = 0$ HARD, $k = 5$ LINEAR) produce limited variations on the PSLR and Cross

Purely Noisy signals

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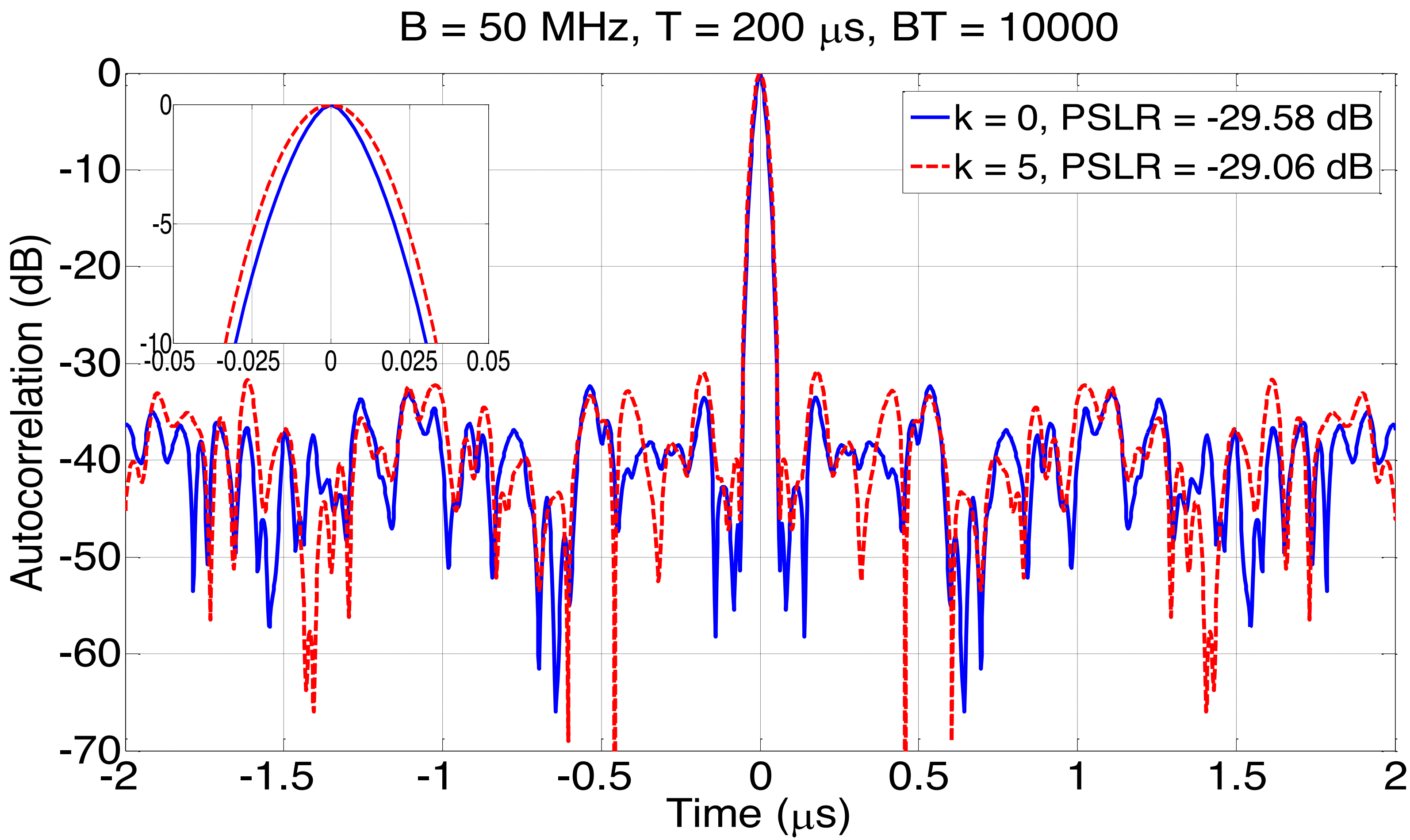
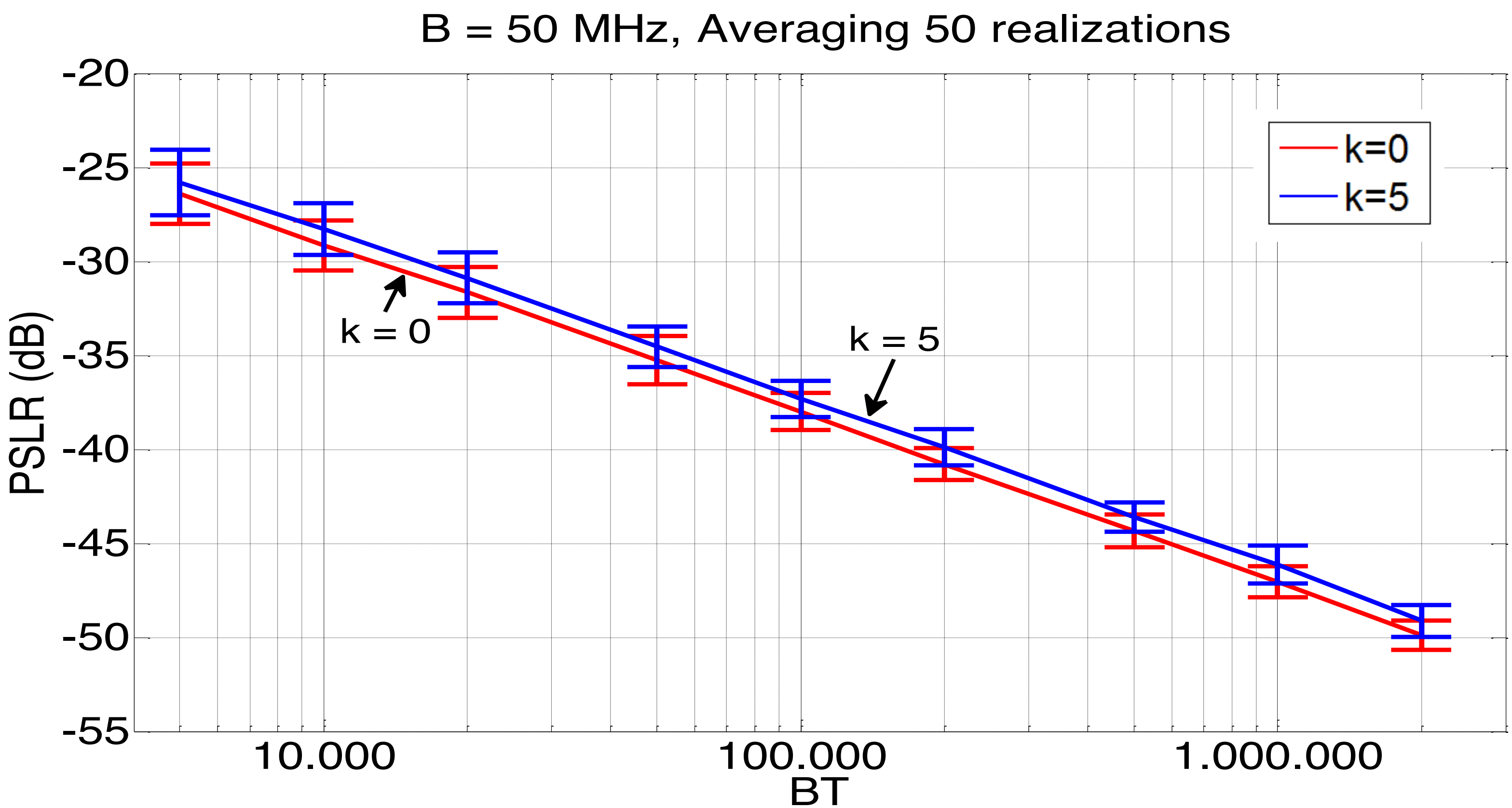
An example of $k = 0$ and $k = 5$ ACF functions: the difference is very small.



Purely Noisy signals

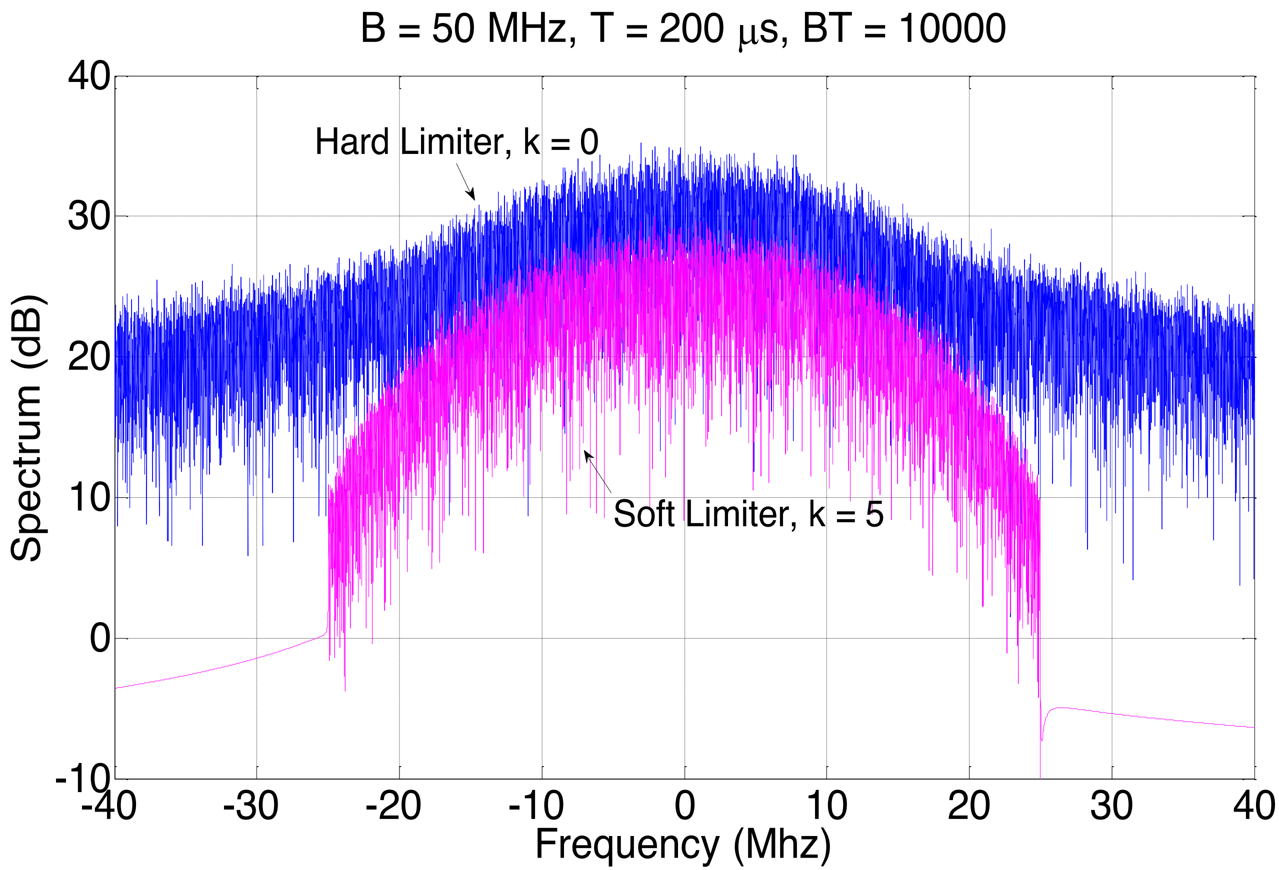
PSLR as a function of BT:



The PSLR of each sequence is worse than $\sim 13\ dB$ compared to $10\ log_{10}\ BT$.

Purely Noisy signals

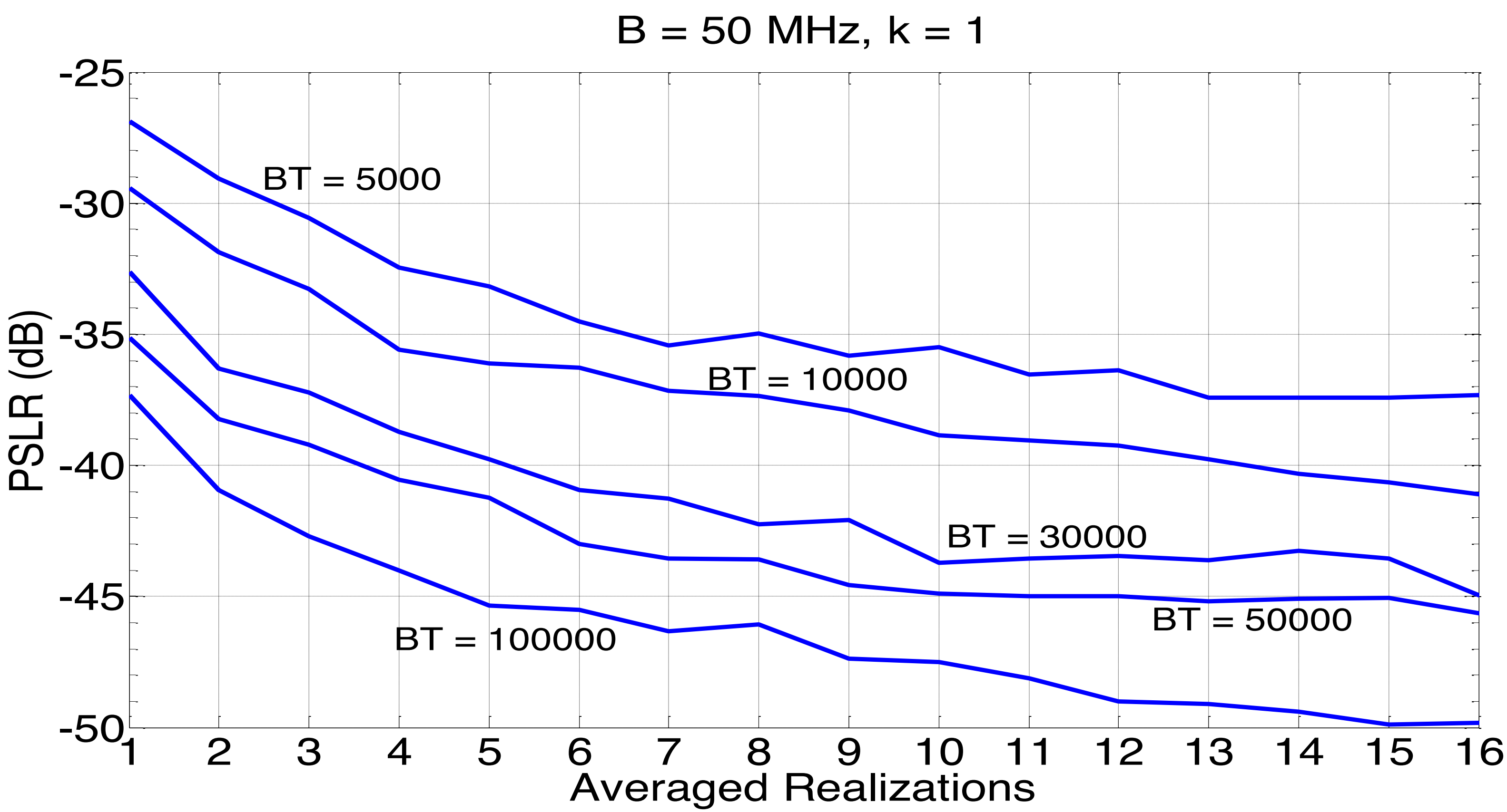
Spectrum



If $k \to 0$ the tails increase **(non-linearity behaviour)**

Purely Noisy signals

Coherent average of ACFs to improve PSLR:



The integration gain is related with the number of averaged realizations.

Purely Noisy signals

Advantages

Unpredictability

- Good LPID properties –

Unlimited number of orthogonal signals

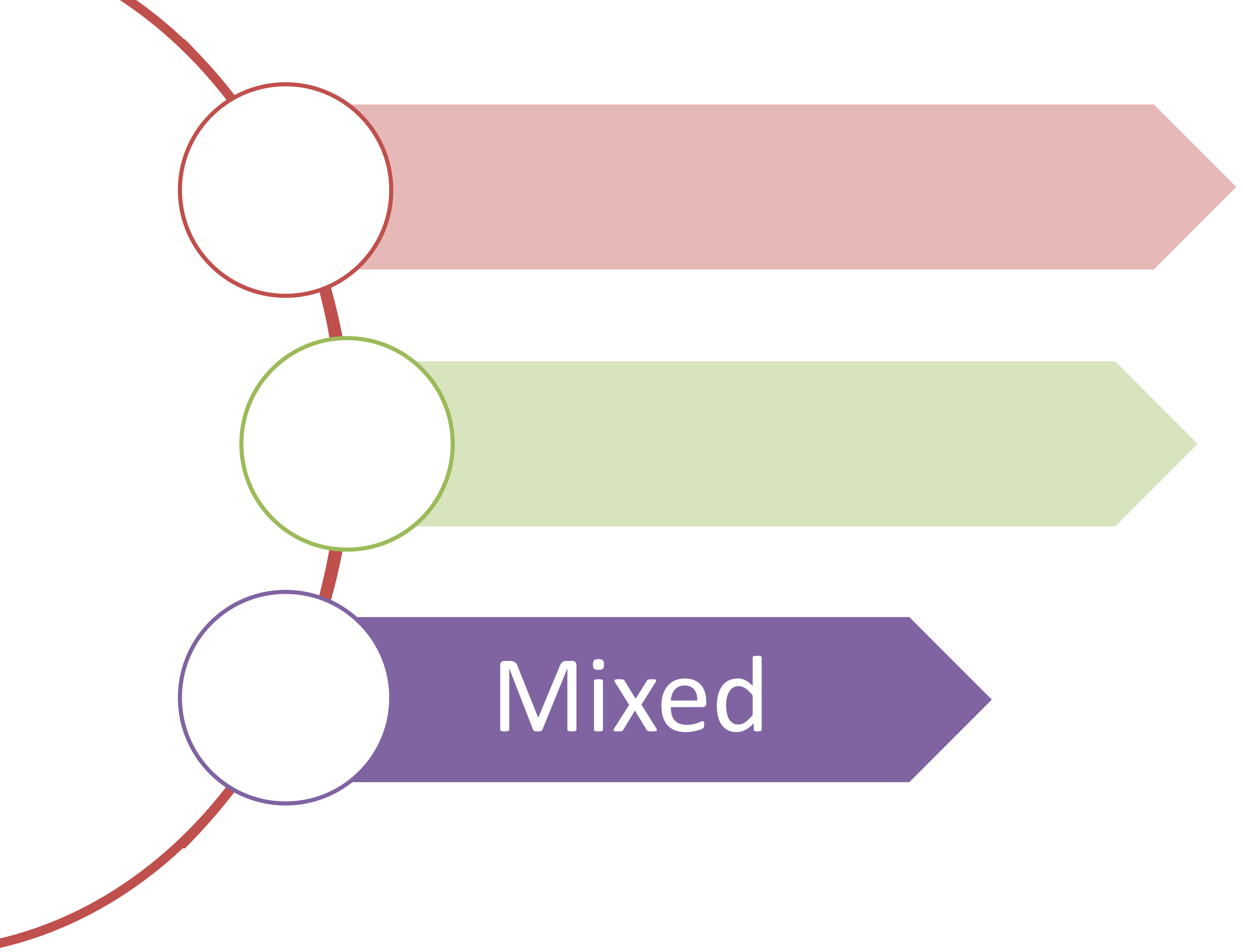
Disadvantages

Low PSLR

Frequency tails

- If hard limited samples –

Generation of Digital Waveforms



Mixed signals

In order to achieve the advantages of both **Deterministic** and **Noisy signals**, you can mix them.

$$s_{H-APCN}(t) = \alpha(t) e^{j\boldsymbol{k}\varphi_{noise}(t)} e^{j\varphi_{HNLFM}(t)}$$

Advanced Pulse Compression Noise [Govoni]

$$s_{H-SD}(t) = \alpha(t) e^{j\boldsymbol{\beta}\varphi_{noise}(t)} e^{j(\mathbf{1}-\boldsymbol{\beta})\varphi_{HNLFM}(t)}$$

Semi Deterministic

Mixed signals

$k, \beta \in [0,1]$ are the ***"random phase limiters"*** which control the amount of noise $e^{j\varphi_{noise}(t)}$ in the signal.

$$s_{H-APCN}(t) = \alpha(t)e^{j\boldsymbol{k}\varphi_{noise}(t)}e^{j\varphi_{HNLFM}(t)}$$

Advanced Pulse Compression Noise [Govoni]

$$s_{H-SD}(t) = \alpha(t)e^{j\boldsymbol{\beta}\varphi_{noise}(t)}e^{j(\mathbf{1}-\boldsymbol{\beta})\varphi_{HNLFM}(t)}$$

Semi Deterministic

Mixed signals

In H-APCN signal the deterministic phase **never vanishes**,
in H-SD signal the deterministic phase **gradually disappears** when β increases.

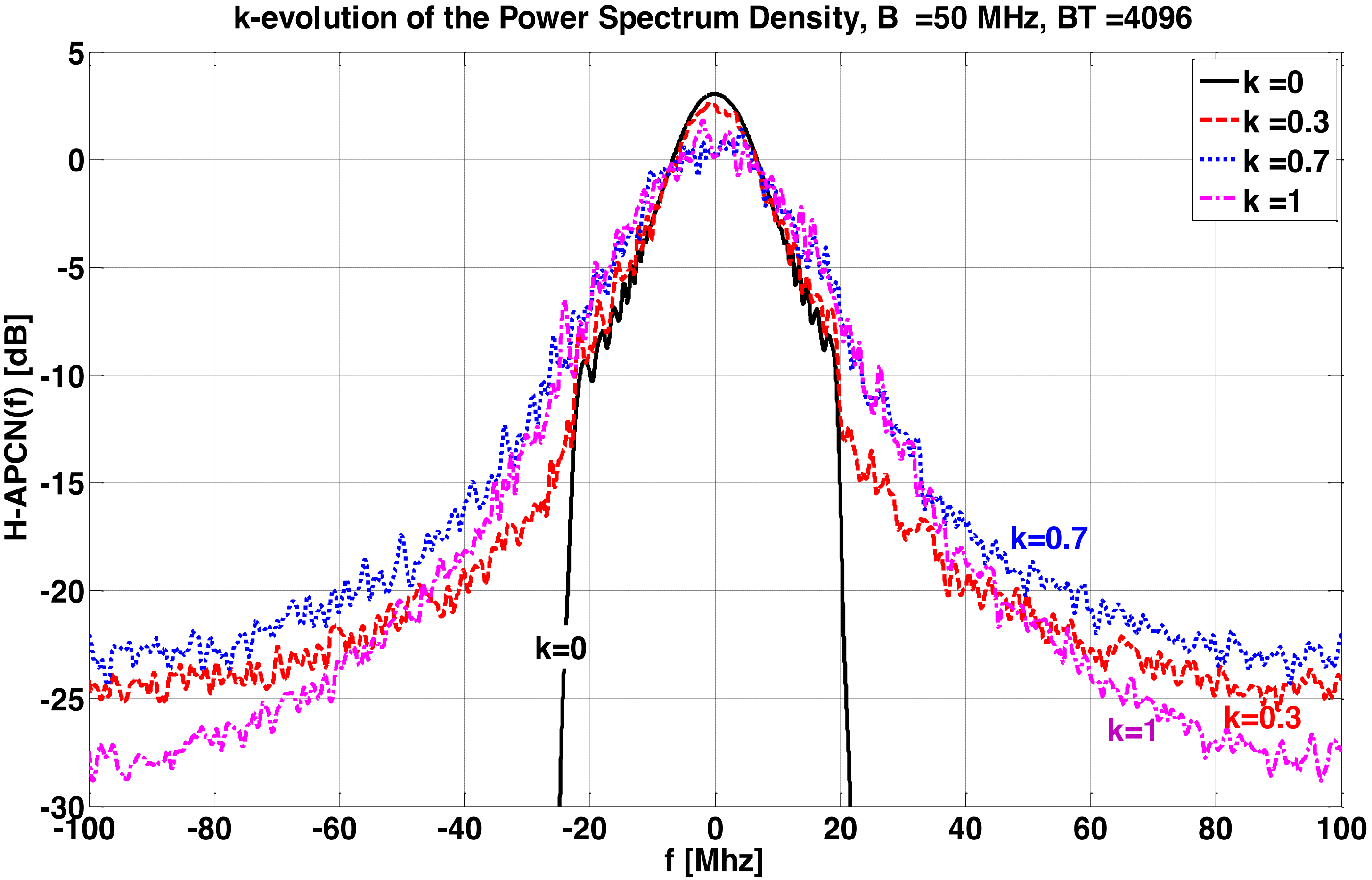
$$s_{H-APCN}(t) = \alpha(t)e^{j\boldsymbol{k}\varphi_{noise}(t)}e^{j\varphi_{HNLFM}(t)}$$

Advanced Pulse Compression Noise [Govoni]

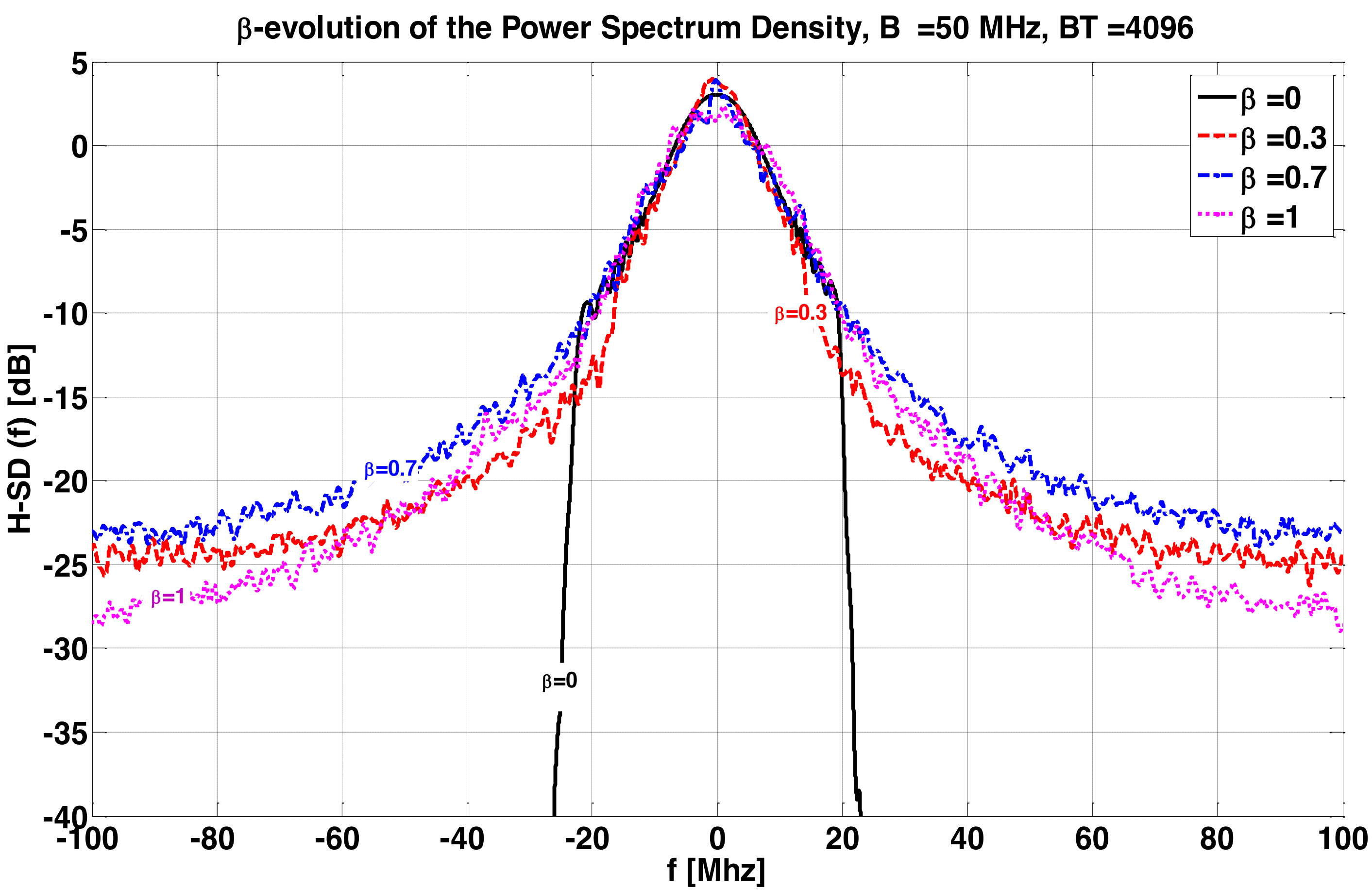
$$s_{H-SD}(t) = \alpha(t)e^{j\boldsymbol{\beta}\varphi_{noise}(t)}e^{j(\mathbf{1}-\boldsymbol{\beta})\varphi_{HNLFM}(t)}$$

Semi Deterministic

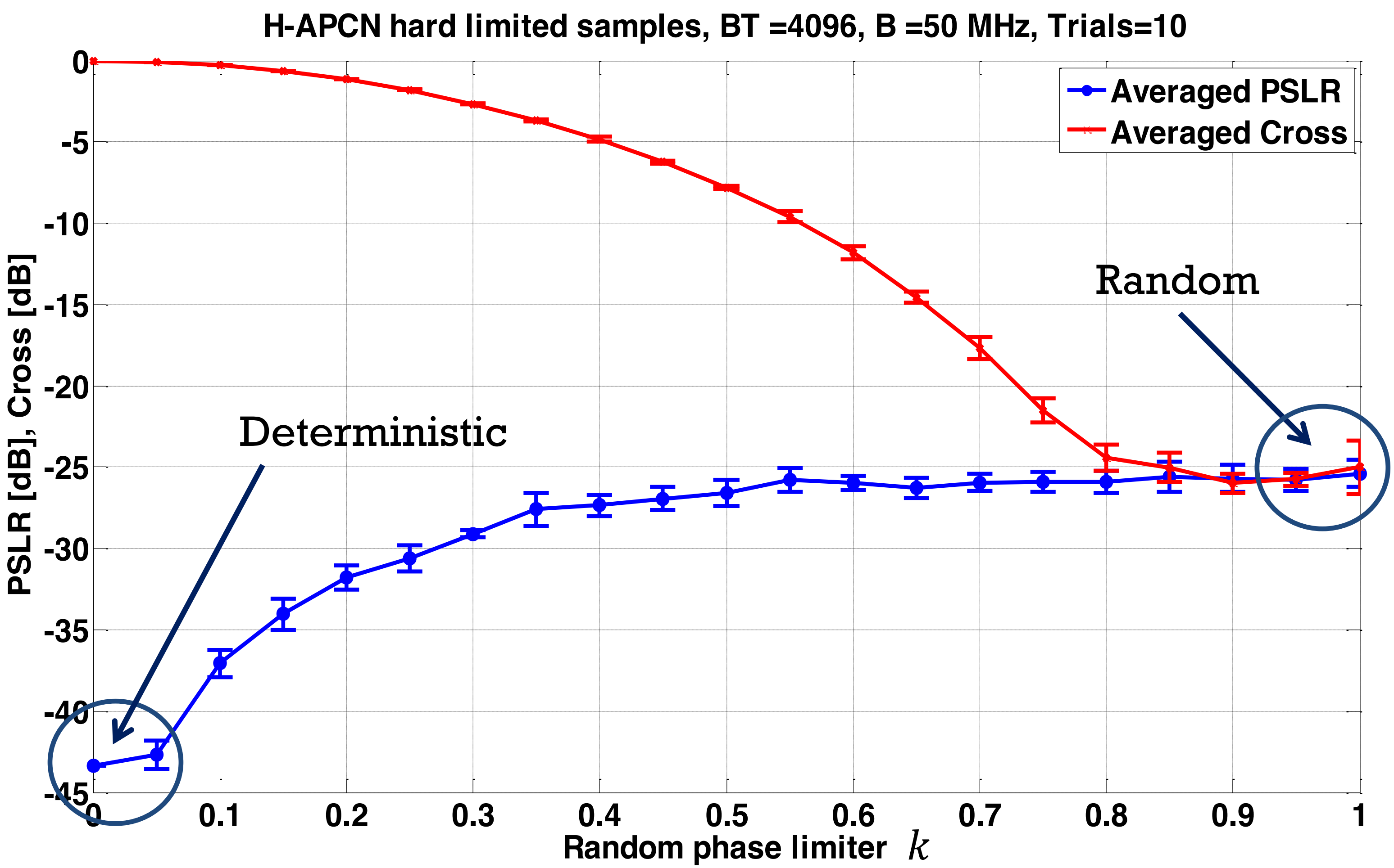
The H-APCN power spectrum



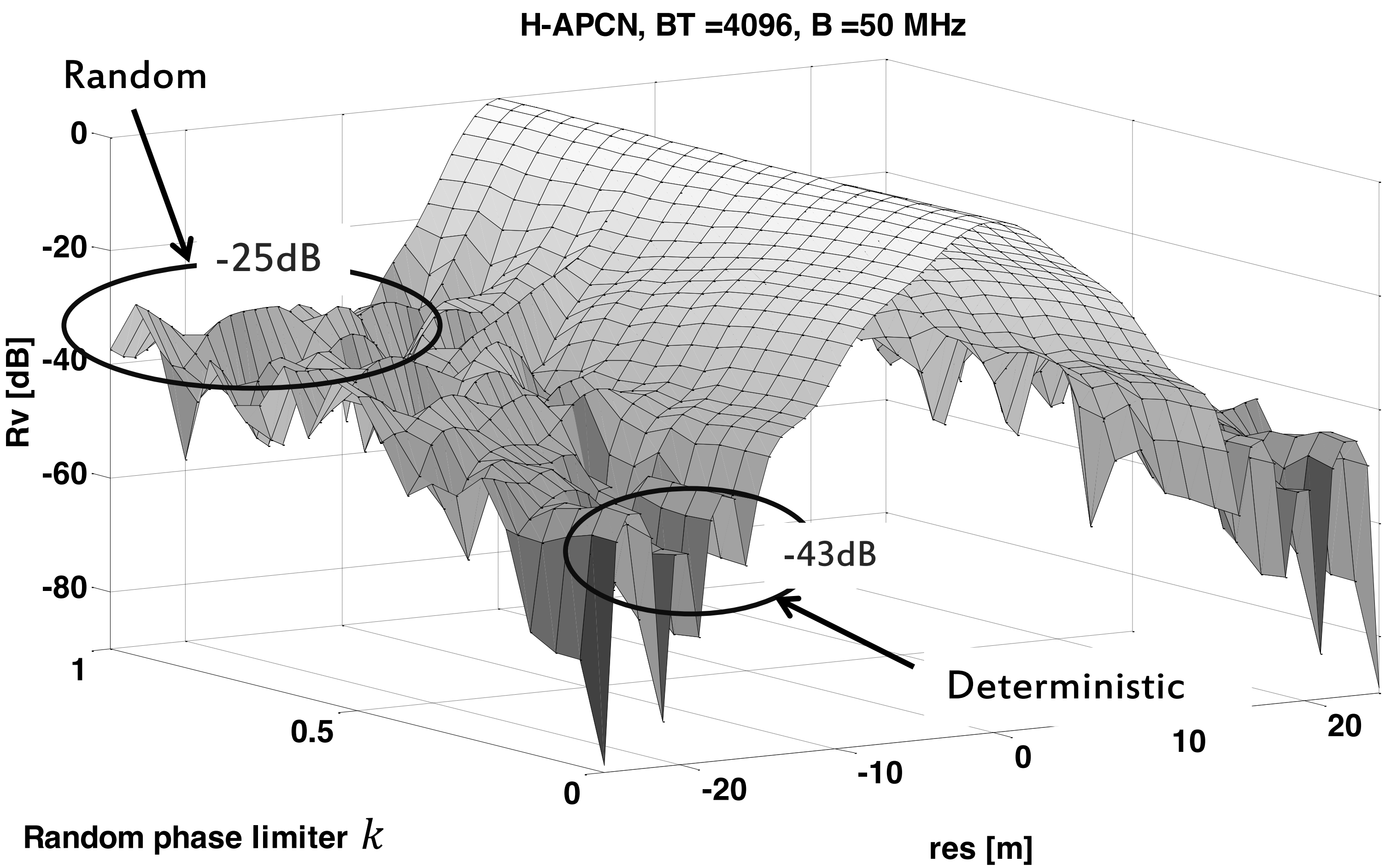
The H-SD power spectrum



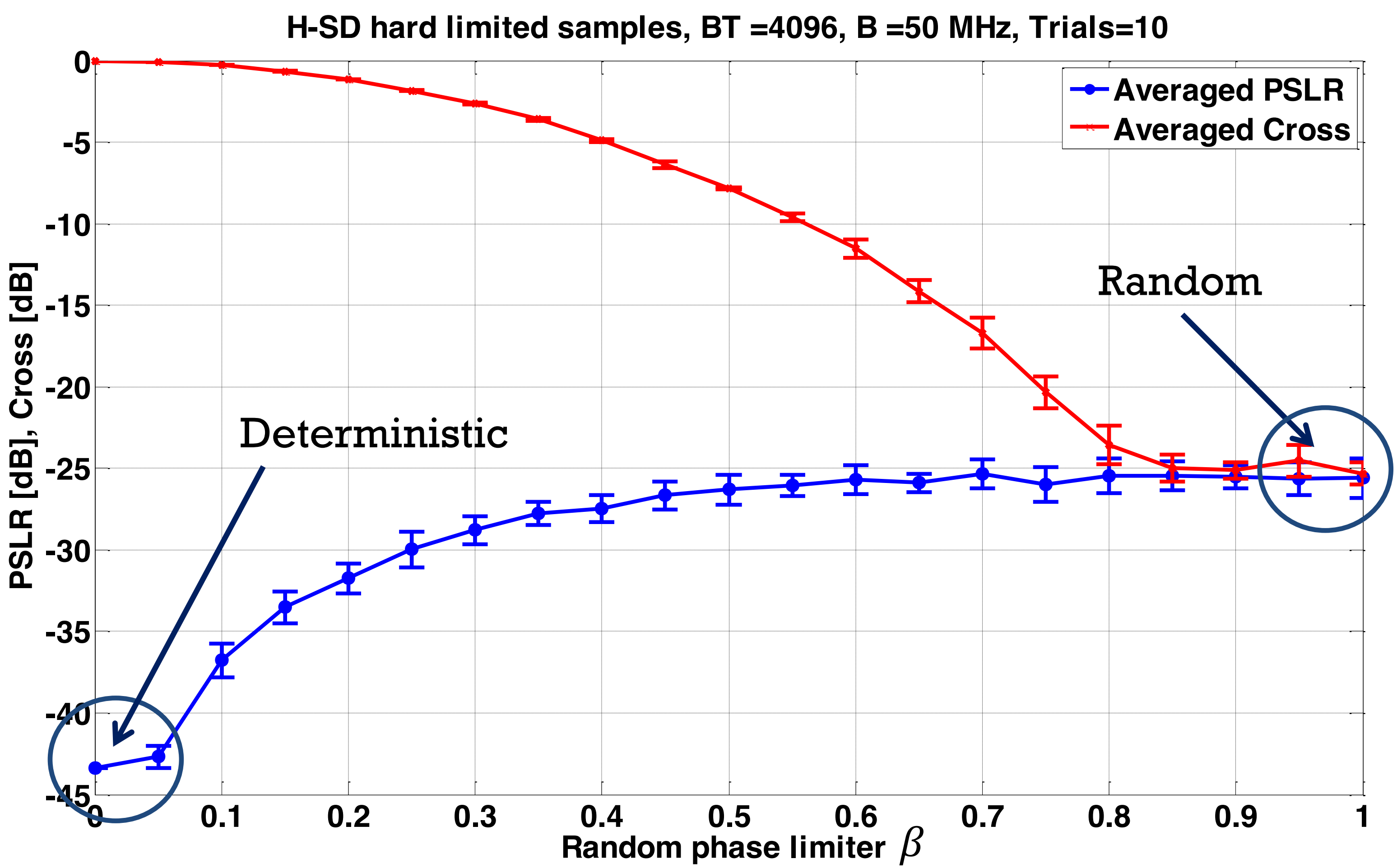
PSLR vs. random phase limiter



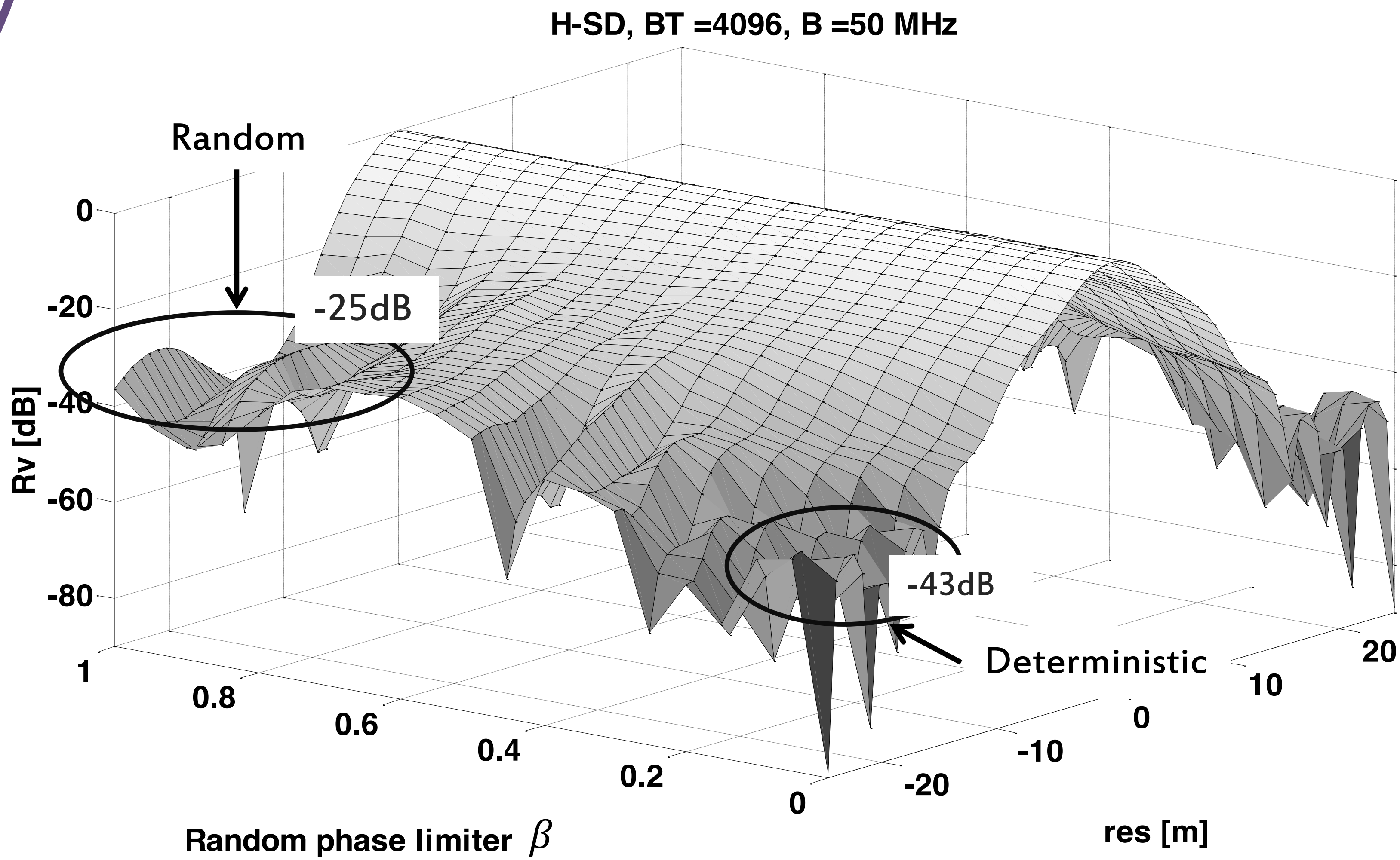
ACF vs. random phase limiter



PSLR vs. random phase limiter



ACF vs. random phase limiter



Mixed signals

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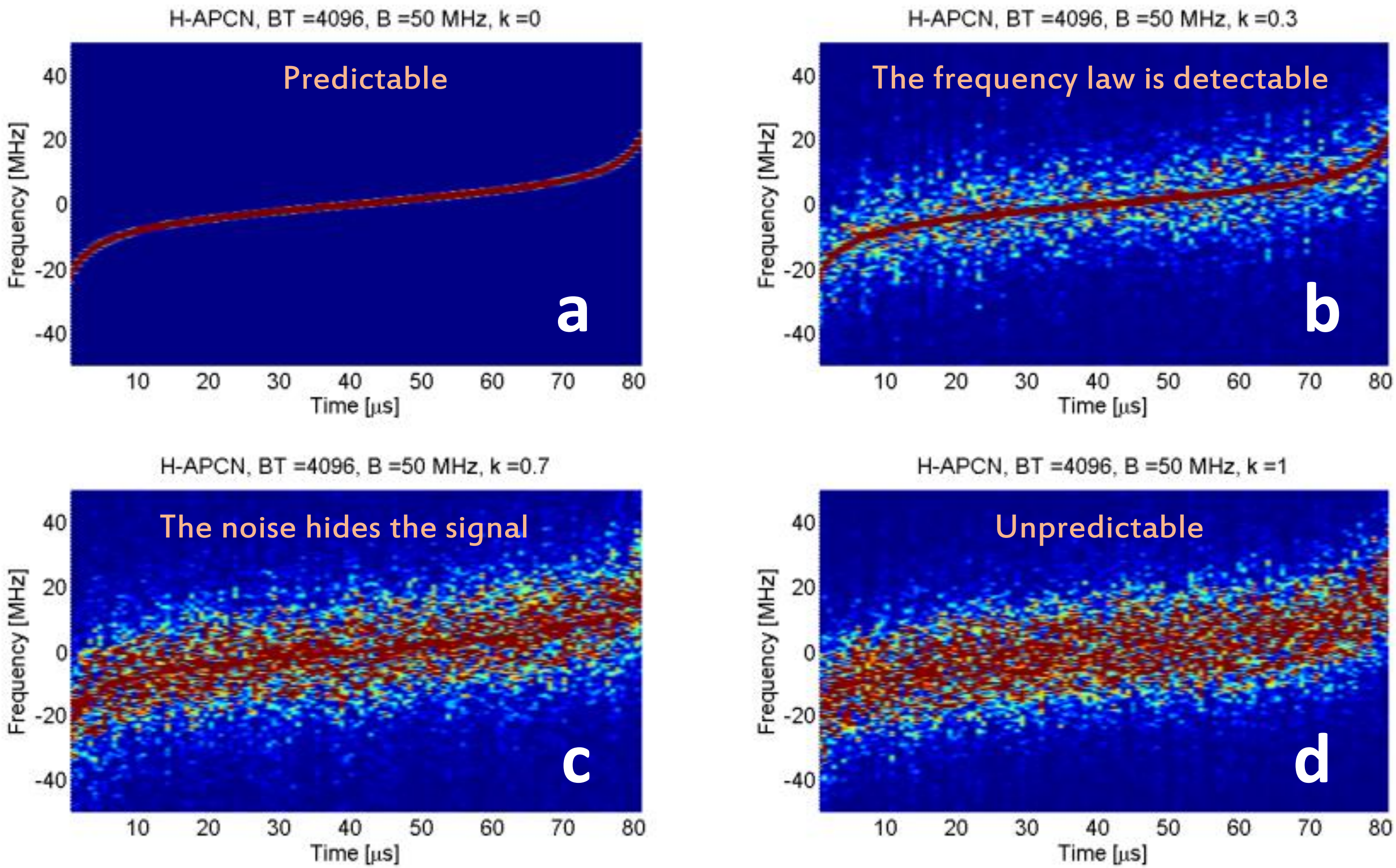
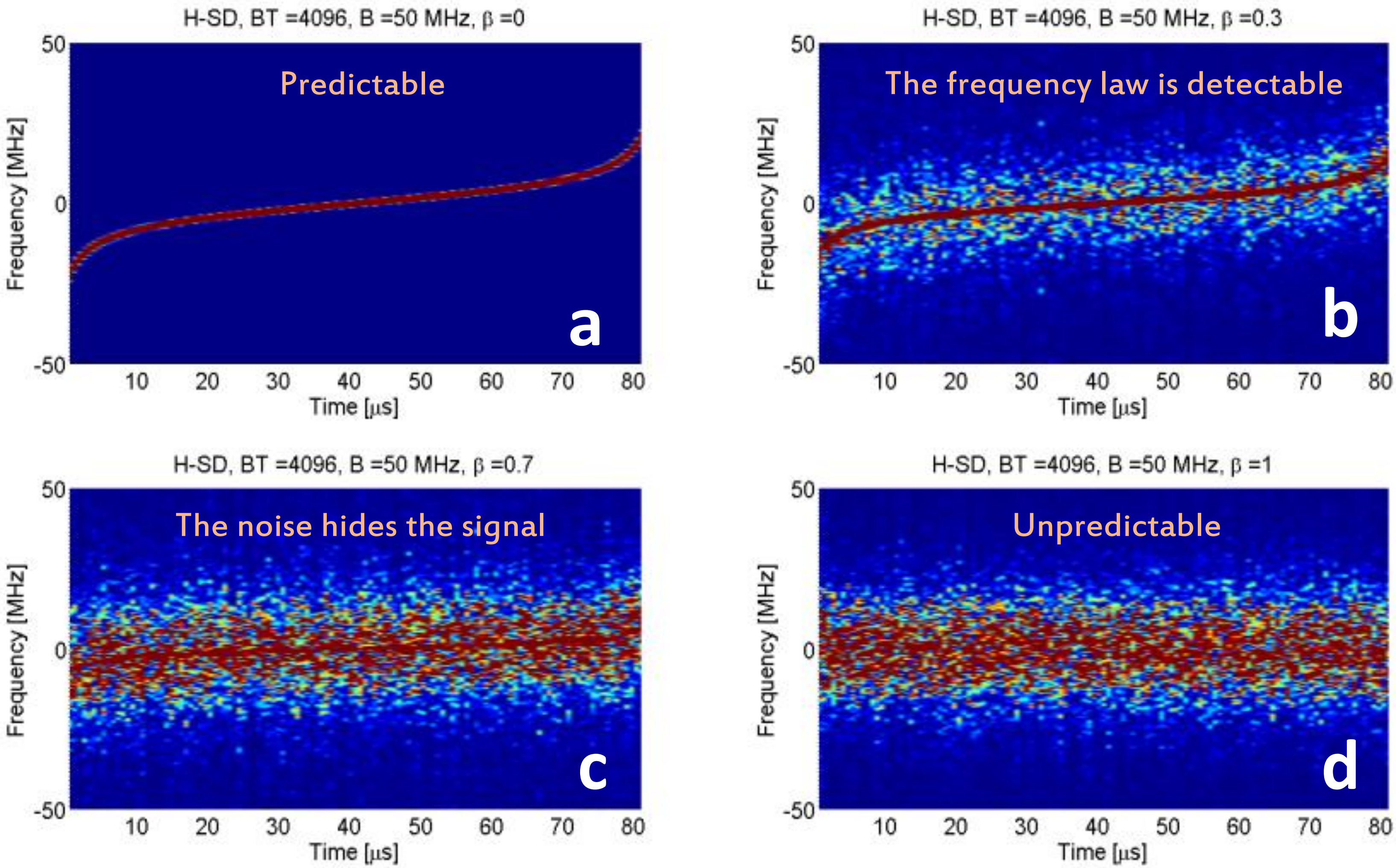


Mixed signals



The MIR (Mutual Information Rate)

$$\rho_n = H(x_n) - H(x_n | x_1, x_2, \dots, x_{n-1})$$

$$\rho_n \in [0, +\infty)$$

It represents the entropy of a single sample, $H(x_n)$, reduced by the knowledge of its past (conditional entropy).

The MIR (Mutual Information Rate)

$$\rho_n = H(x_n) - H(x_n | x_1, x_2, \dots, x_{n-1})$$

For a Real Strictly Sense Stationary Gaussian process with spectrum $S(\omega)$ the MIR becomes:

$$\boxed{\rho_n = \frac{1}{2} ln\left[\frac{1}{2\pi}\int_{-\pi}^{+\pi} S(\omega) d\omega\right] - \frac{1}{4\pi}\int_{-\pi}^{+\pi} ln[S(\omega)]\, d\omega}$$

Mixed signals

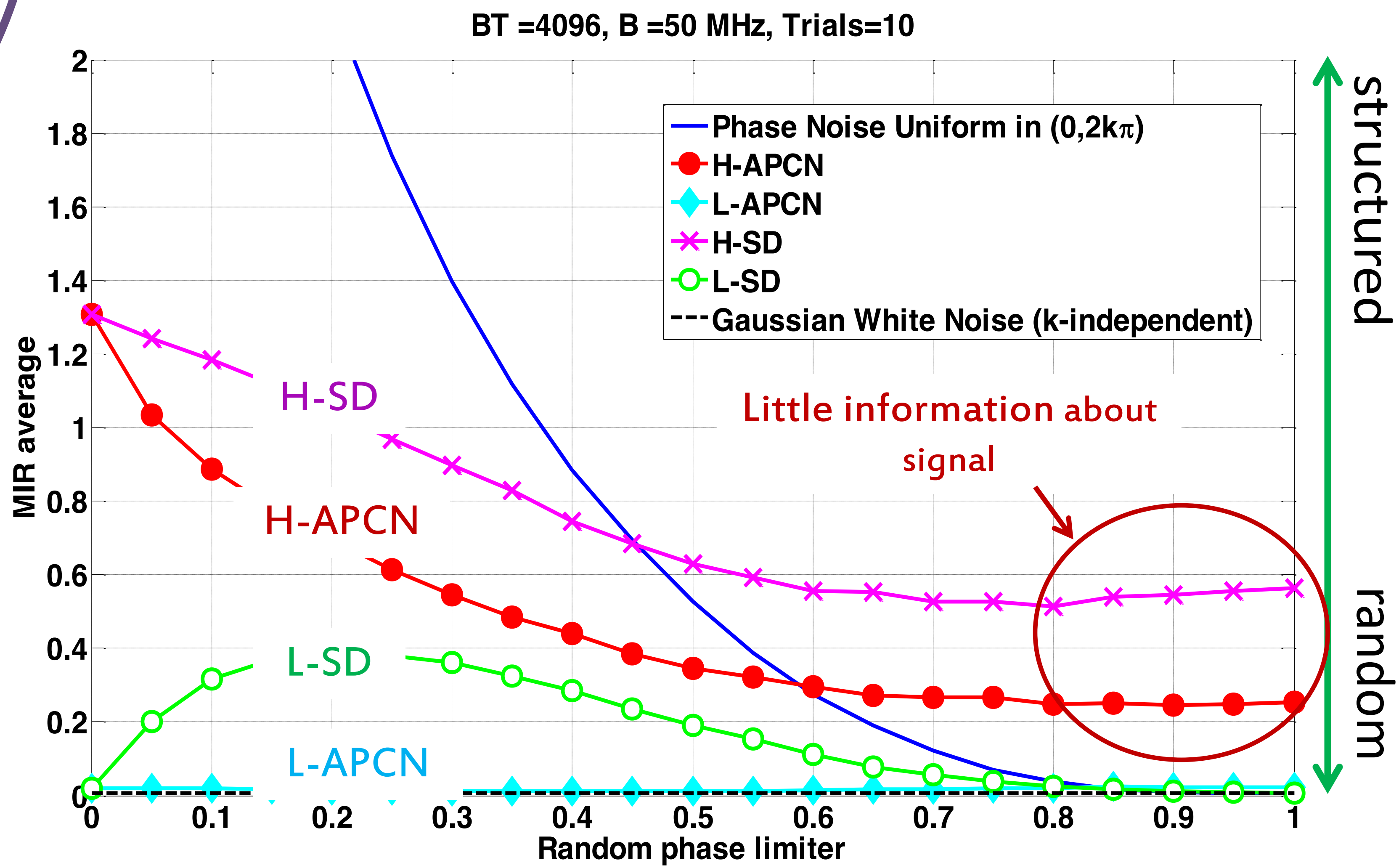
MIR satisfies the following properties:

1. $\boldsymbol{\rho_n > 0}$ structured signal

2. $\boldsymbol{\rho_n = 0}$ if $S(\omega) = cost$ (i.e. purely random)

The concept of MIR can be extended to complex processes [Nesser, Wei Xiong, Picinbono]

Mixed signals



Generation of Digital Waveforms

FUTURE WORKS

1. Prove on these waveforms (Purely noisy and mixed) the ***goodness of the recognition waveforms*** algorithms

2. Try to ***limit*** the spectrum in order to meet the ITU-R Recommendation (SM.1541-5)

Thank you!