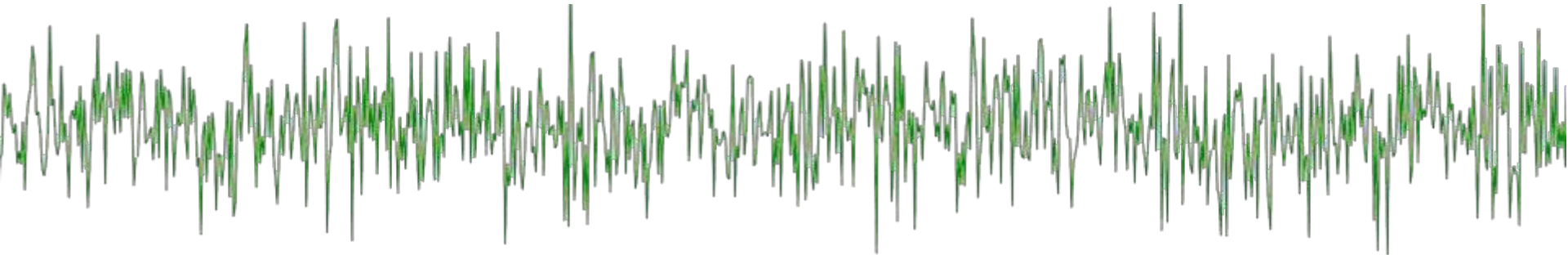


NOISE RADAR TECHNOLOGY: WAVEFORMS DESIGN

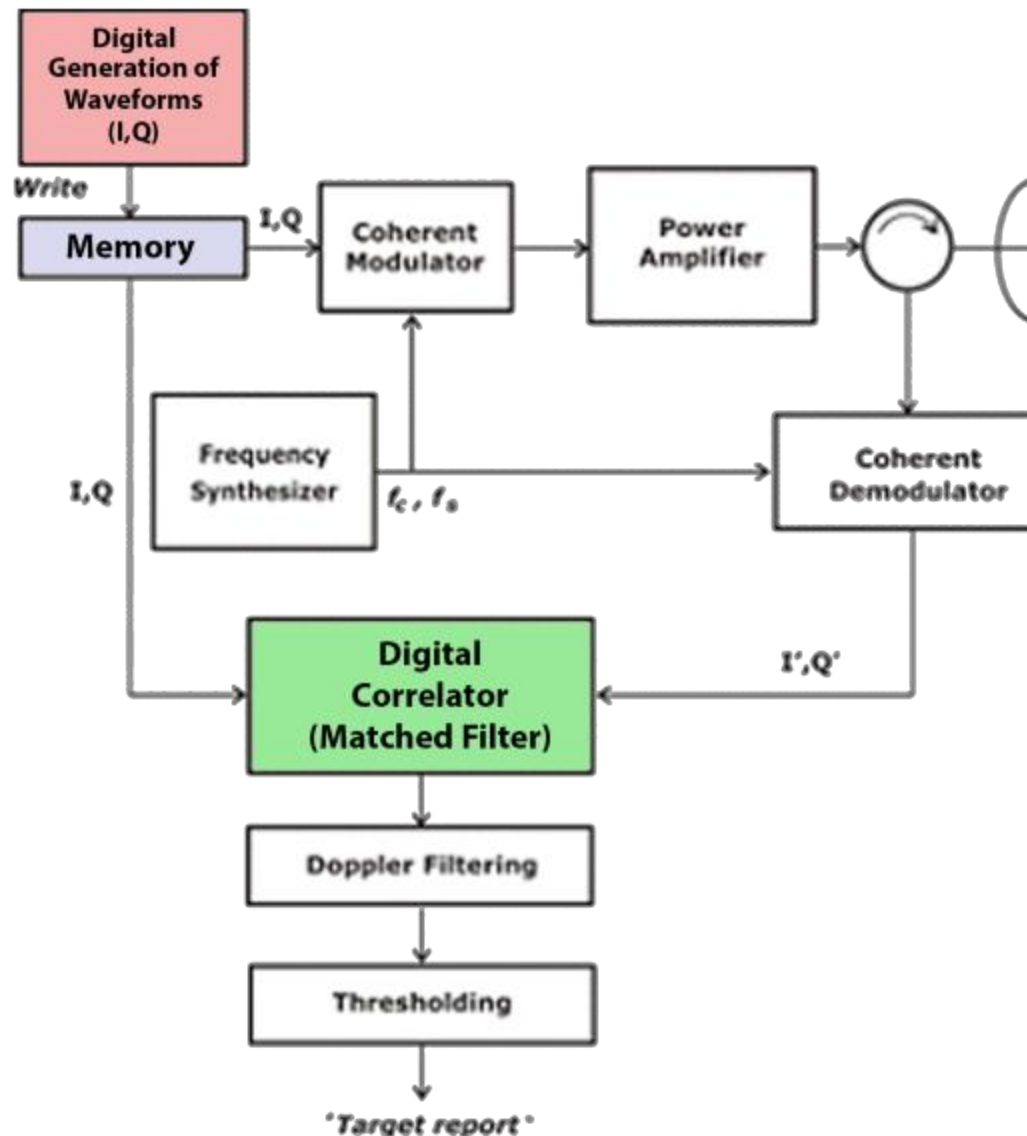


Galati G., Pavan G., De Palo F.

“Tor Vergata University” - Rome

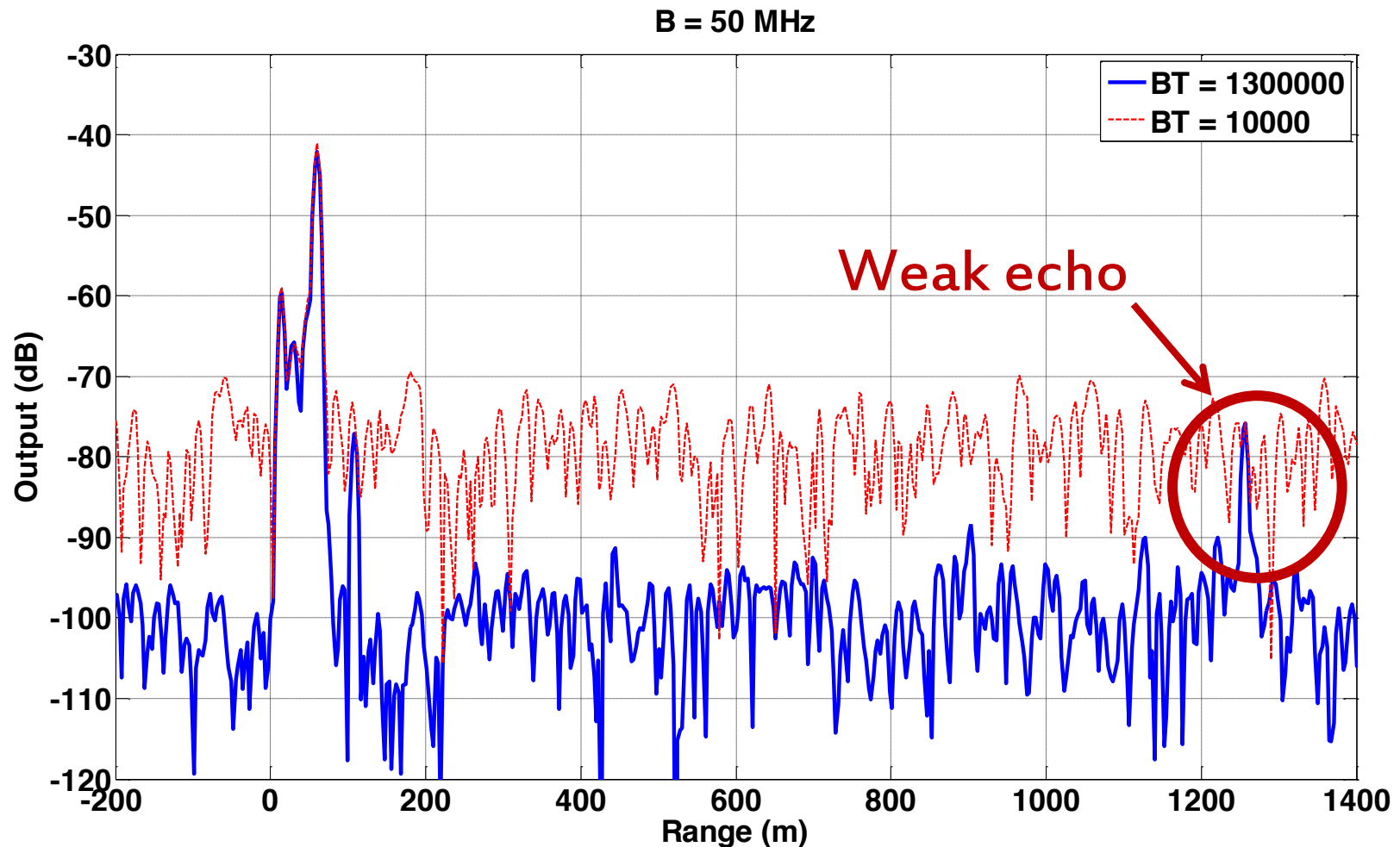
July 7-11, 2014 Bressanone (BZ)

COHERENT NOISE RADAR ARCHITECTURE

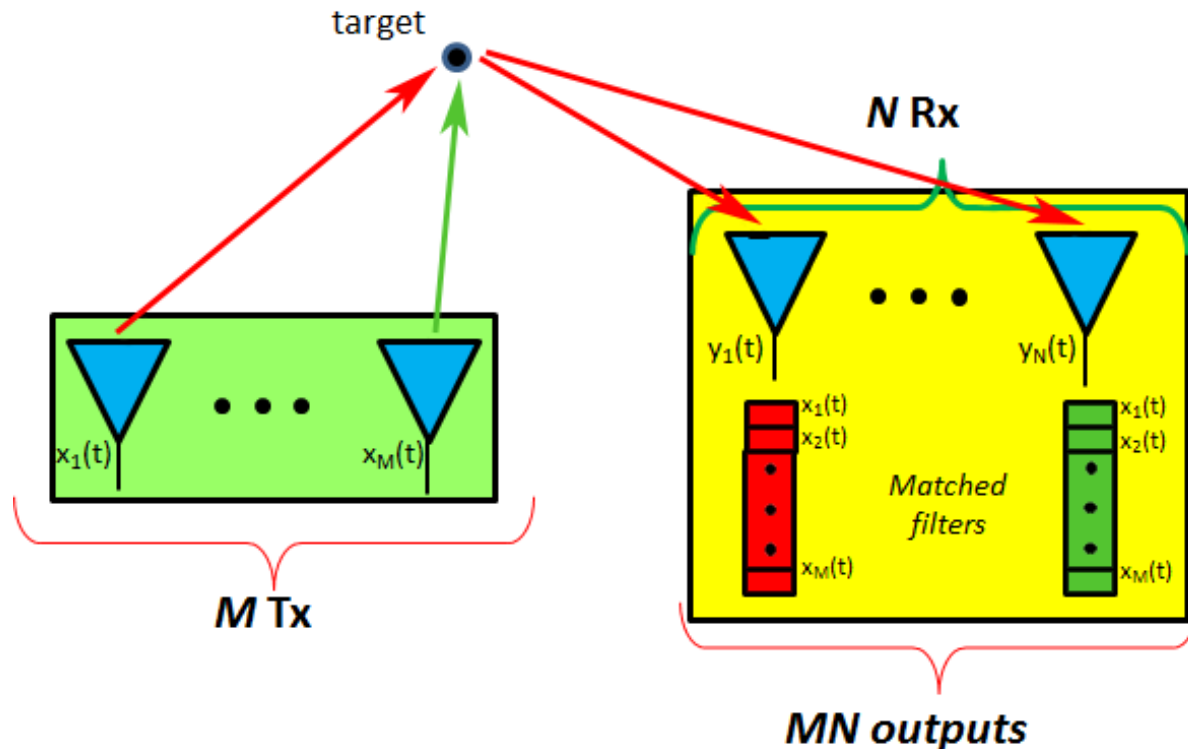


COHERENT NOISE RADAR ARCHITECTURE

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 attributes, 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

A diagram illustrating the generation of digital waveforms. It features a vertical line on the left with three circular nodes. Each node is connected to a horizontal arrow pointing to the right. The top node is red and labeled 'Deterministic'. The middle node is green and labeled 'Purely Noisy'. The bottom node is purple and labeled 'Mixed'. The entire diagram is set against a white background with a red curved line on the left side.

Deterministic

Purely Noisy

Mixed

GENERATION OF DIGITAL WAVEFORMS



The diagram illustrates the generation of digital waveforms through three distinct methods, arranged vertically. A curved red line on the left side of the slide acts as a central axis, with three white circles positioned along it. Each circle is connected to a horizontal arrow pointing to the right. The top arrow is red and contains the word 'Deterministic'. The middle arrow is green and is empty. The bottom arrow is purple and is also empty. The circles are outlined in red, green, and purple respectively, matching the color of their corresponding arrows.

Deterministic



Deterministic signals

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- **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.

$$\phi'(t) = \pi B \left\{ \alpha \frac{1}{tg(\gamma)} tg\left(\frac{2\gamma B}{T}\right) + (1 - \alpha) \frac{2t}{T} \right\}$$

Non Linear term

Linear term

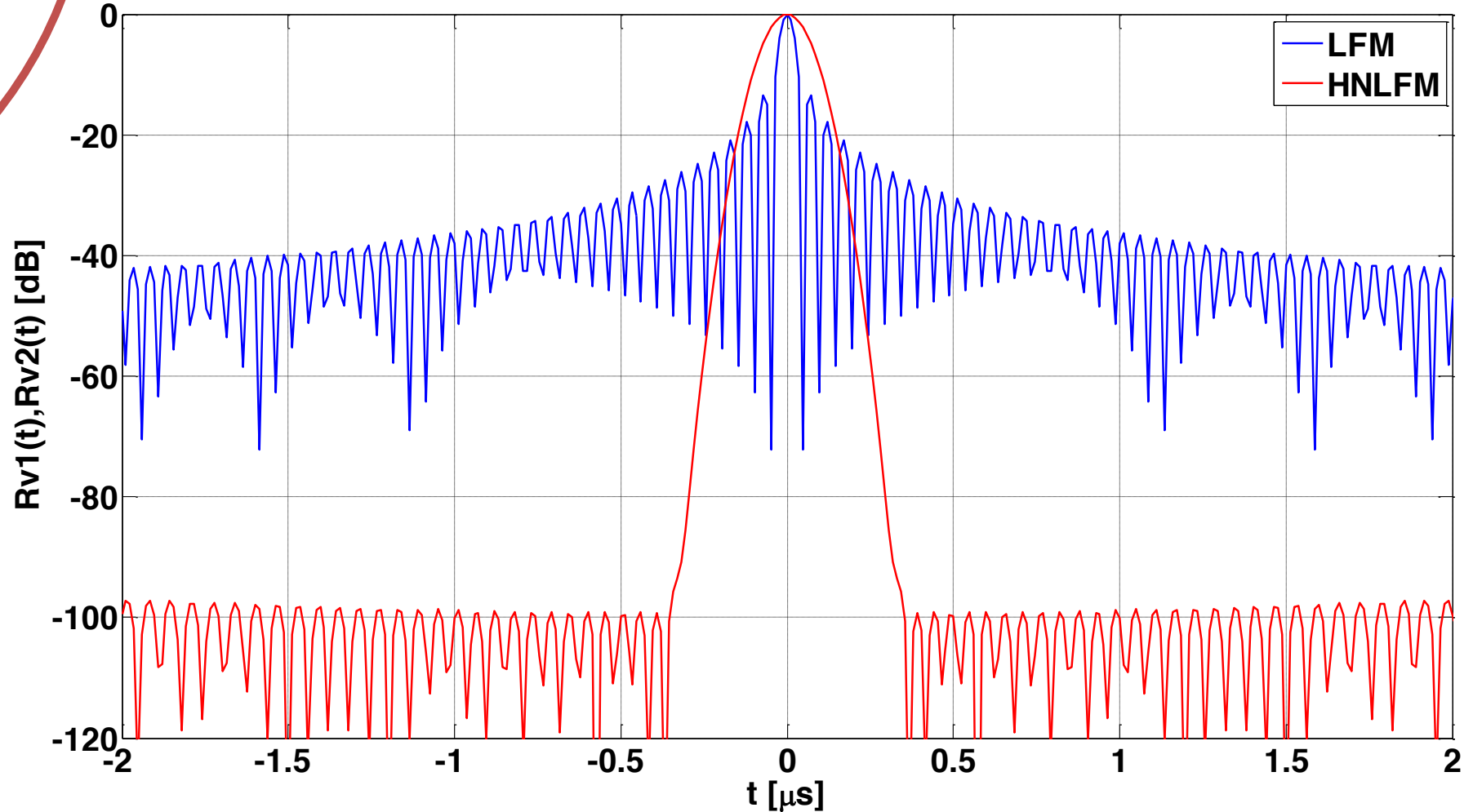
- * Zhiqiang, Peikang, Weining *"Matched NLFM Pulse Compression Method with Ultra-low Sidelobes"*
- ** T. Collins, P. Atkins *"Nonlinear frequency modulation chirps for active sonar"*

Deterministic signals

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Autocorrelation $B = 20.48$ MHz, $T = 100$ μ s, $BT = 2048$ PSLRv1=-13.467 PSLRv2=-93.5713

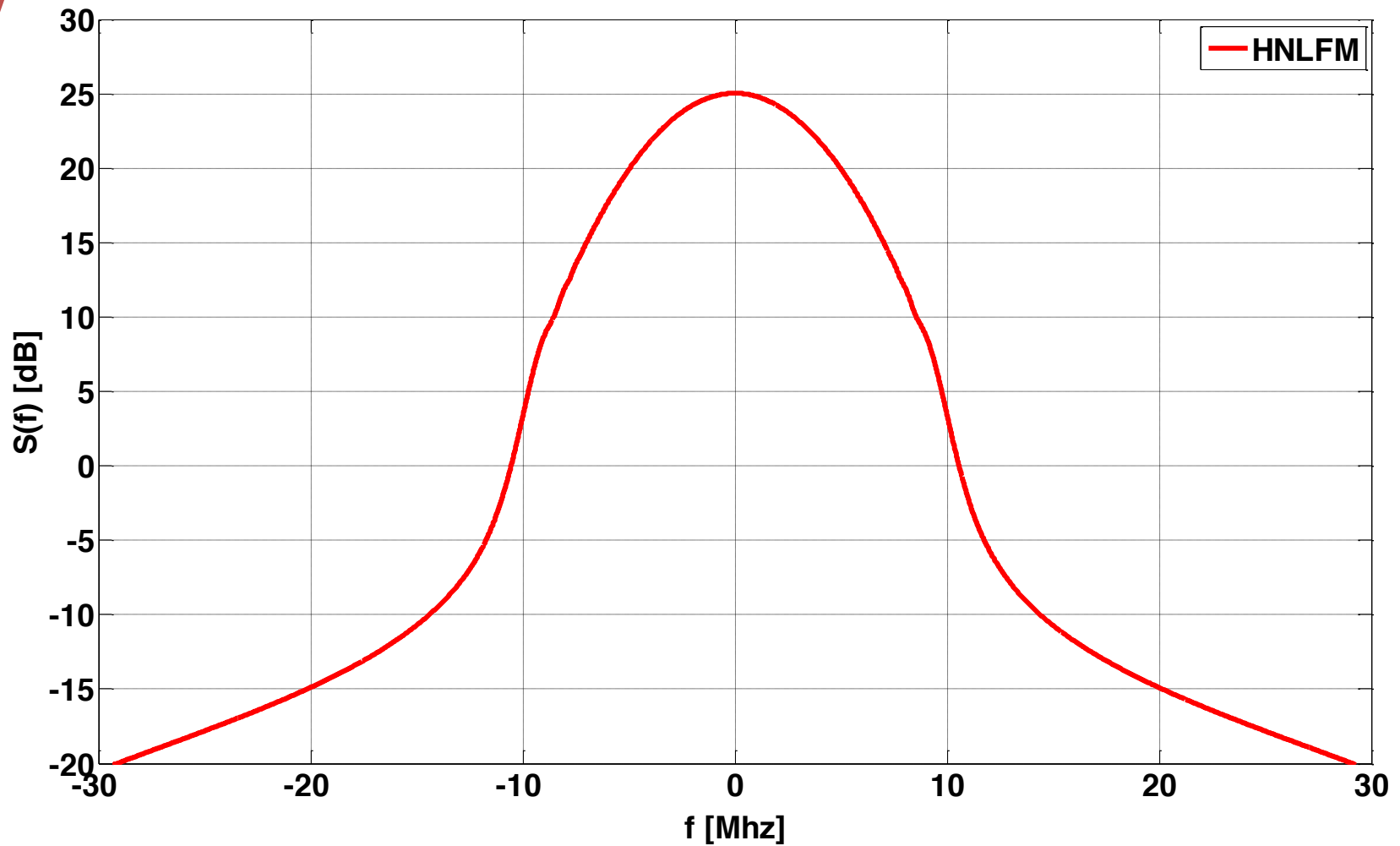


Deterministic signals

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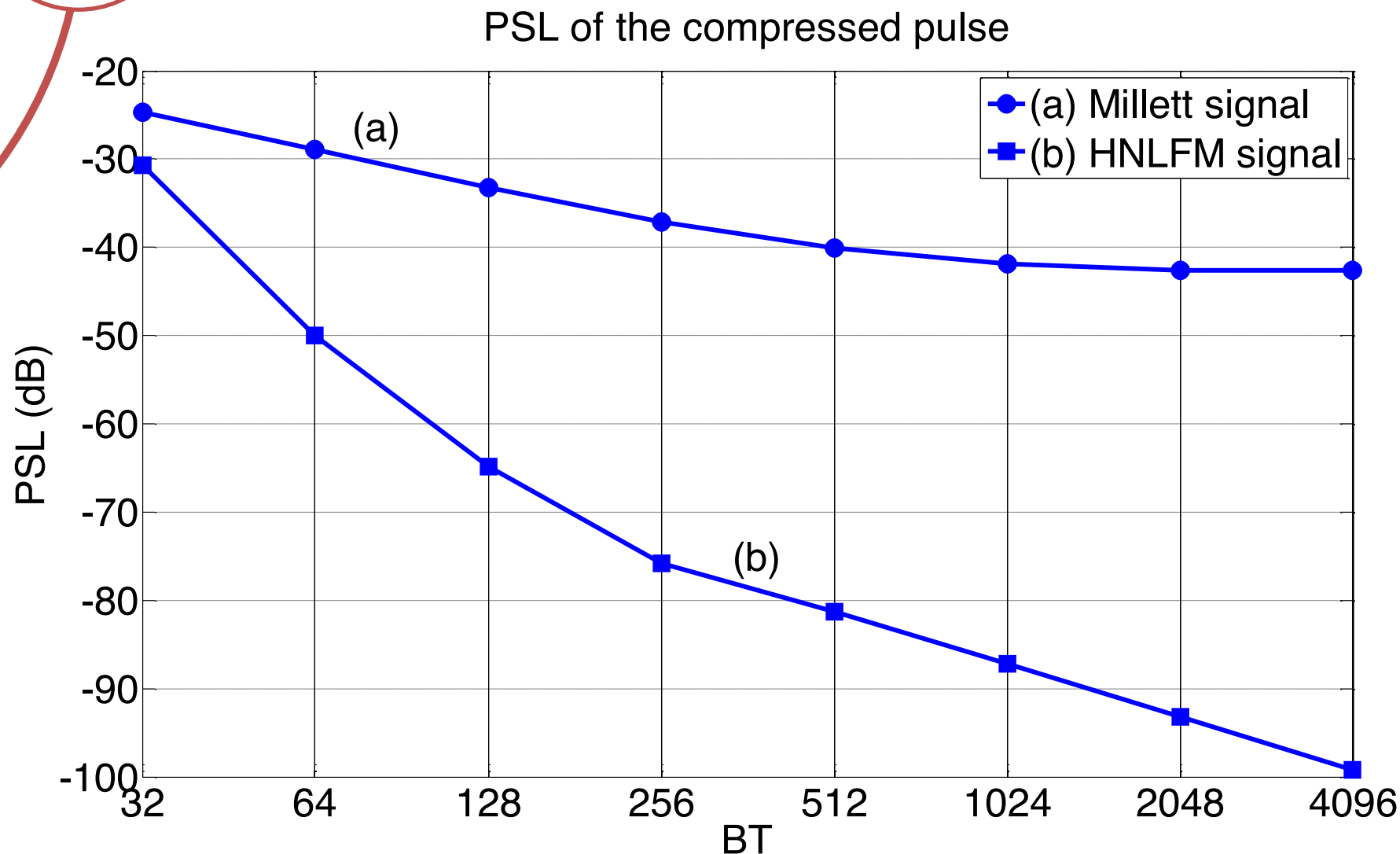
Spectrum modulus, $B = 20.48$ MHz, $T = 100$ μ s, $BT = 2048$



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Deterministic signals

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Advantages

Good PSLR

- Avoid masking effect -

Limited bandwidth

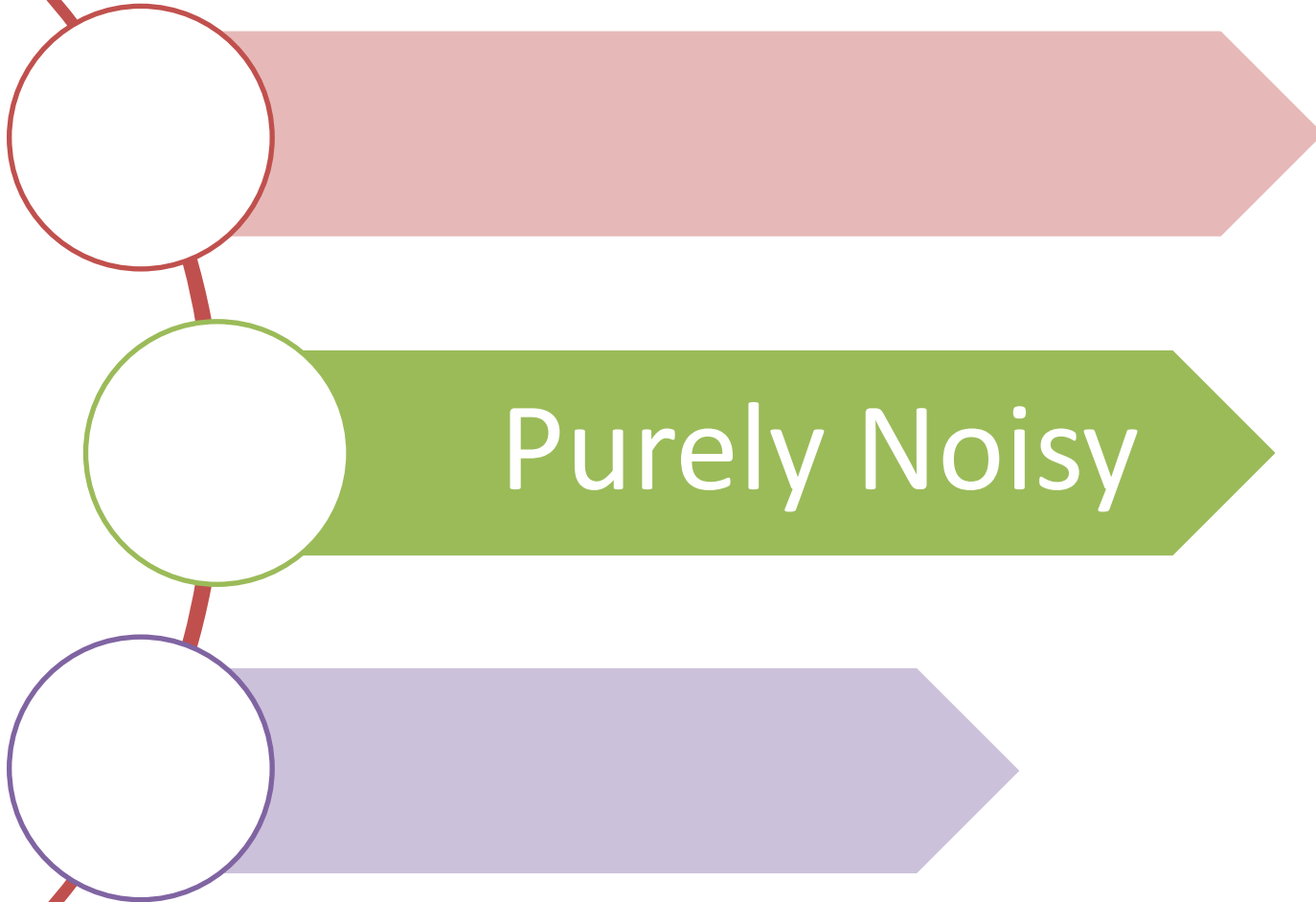
Disadvantages

Predictability

- Poor LPID properties –

Only 2 orthogonal signals

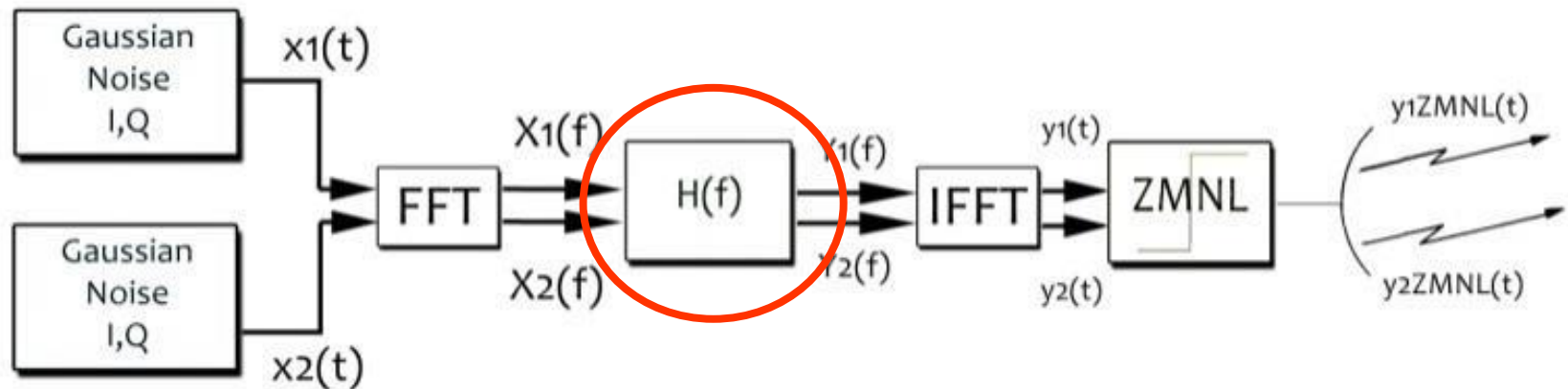
GENERATION OF DIGITAL WAVEFORMS



Purely Noisy signals

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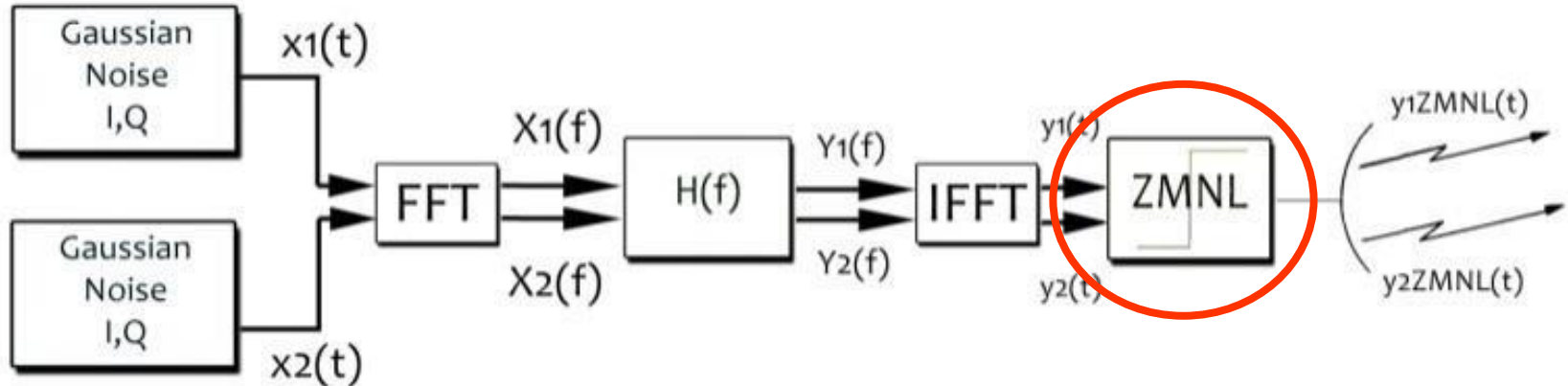


$H(f)$ is a **Blackman-Nuttall** window whose inverse Fourier transform gives very low sidelobes.

Purely Noisy signals

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

*Mean Envelope
to Peak Power Ratio*

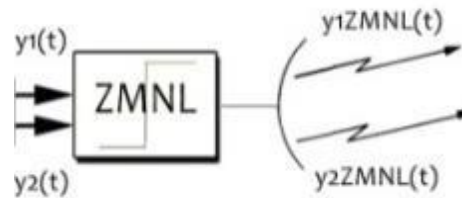
To maximize the trasmitter efficiency,
MEPPR has to be close to the unity

Purely Noisy signals

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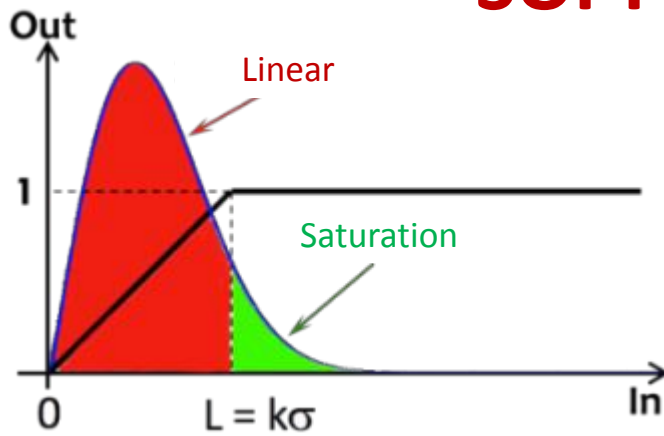
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Zero-Memory-Non-Linearity transformation



The amplitude limiter may be:

SOFT



HARD

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

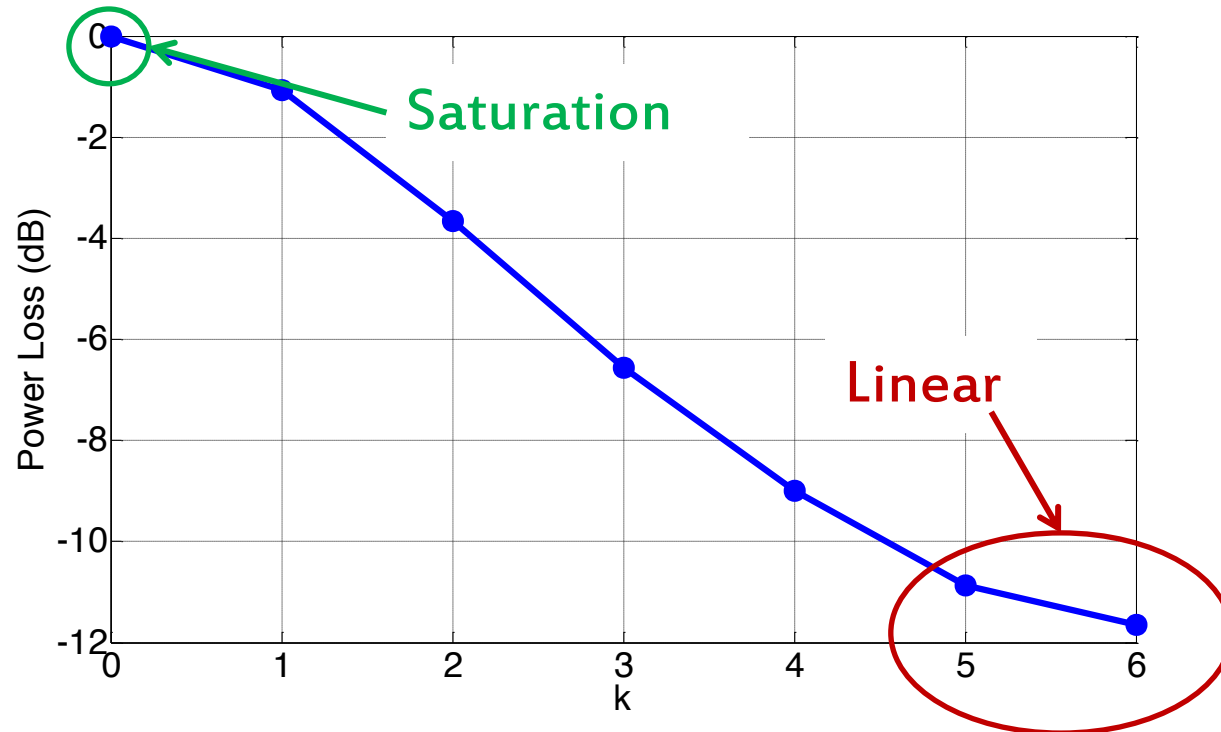
Purely Noisy signals

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Losses:

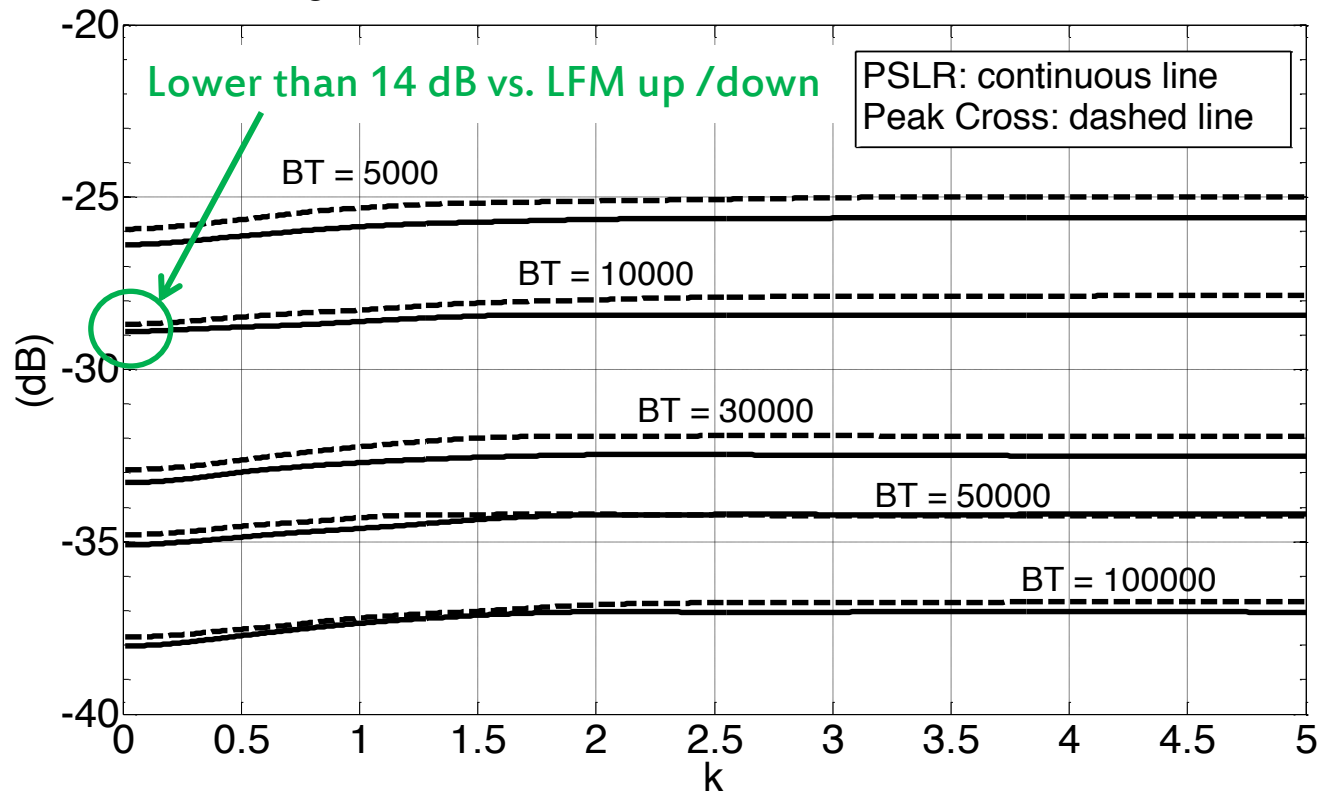
In many applications the minimization of the tx power loss may be an important requirement.



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

Choice of the limiter threshold $[k]$

Average: PSLR and Peak Cross-correlation, $B = 50$ MHz



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

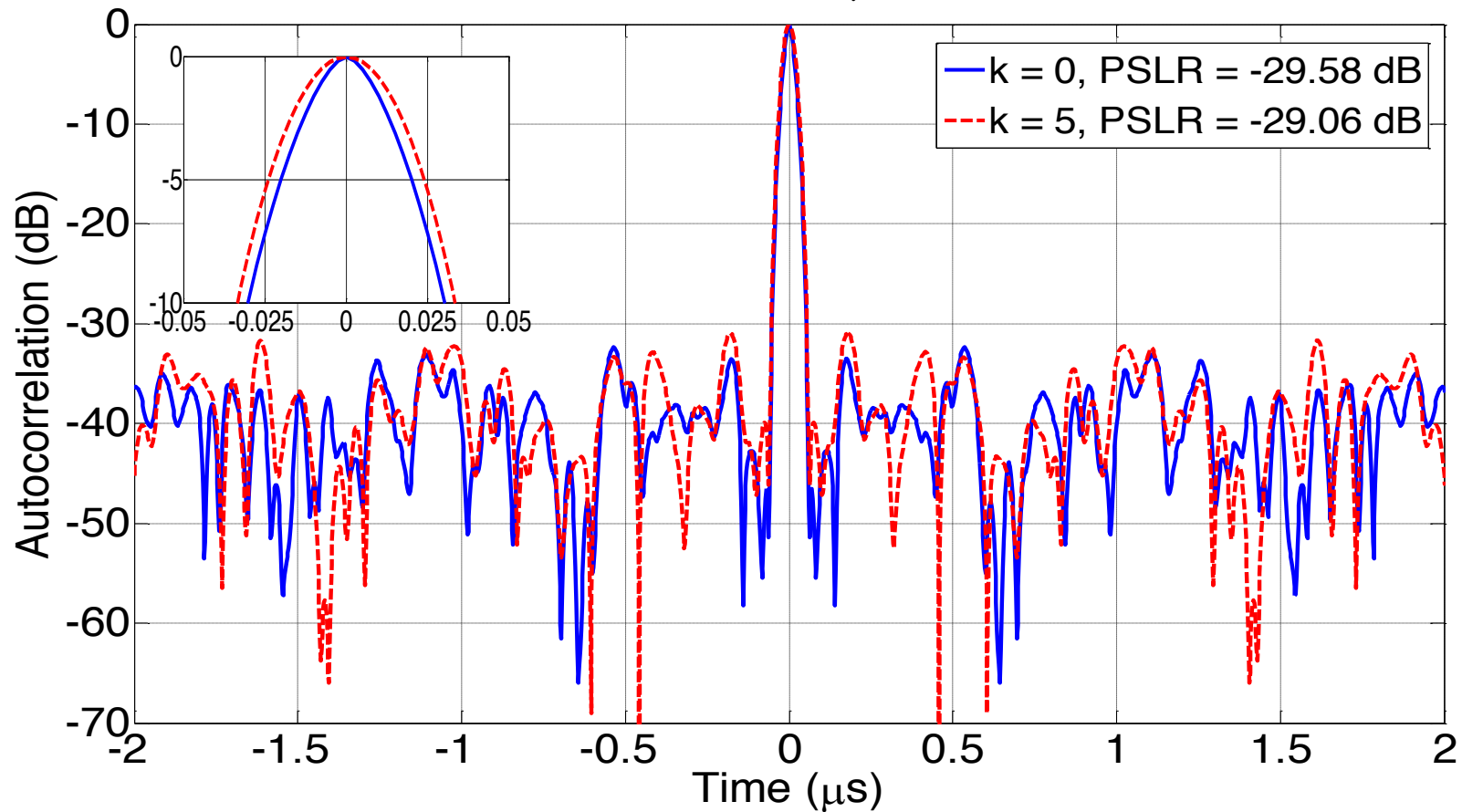
Purely Noisy signals

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

$B = 50$ MHz, $T = 200$ μ s, $BT = 10000$



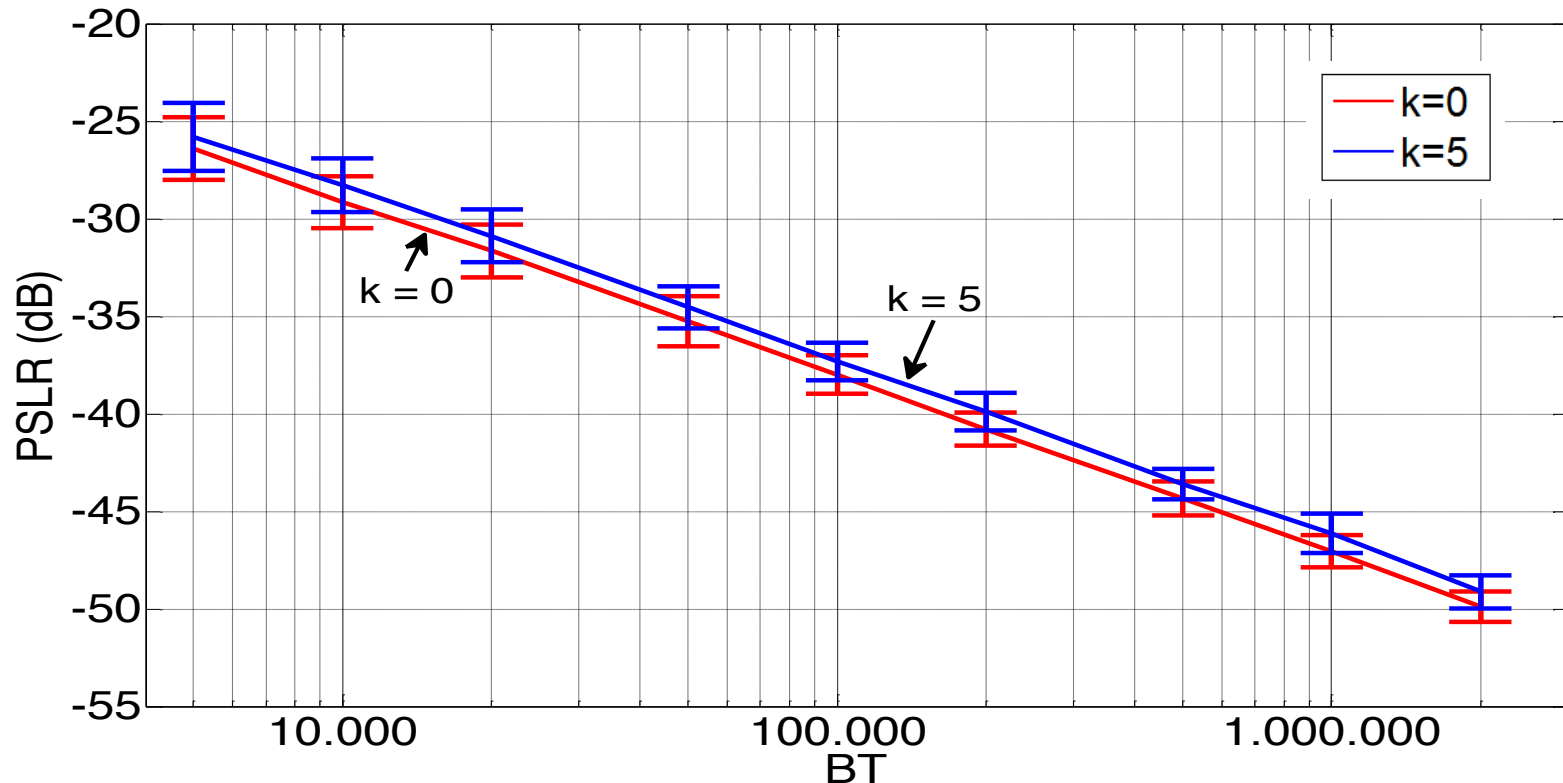
Purely Noisy signals

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PSLR as a function of BT:

B = 50 MHz, Averaging 50 realizations



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

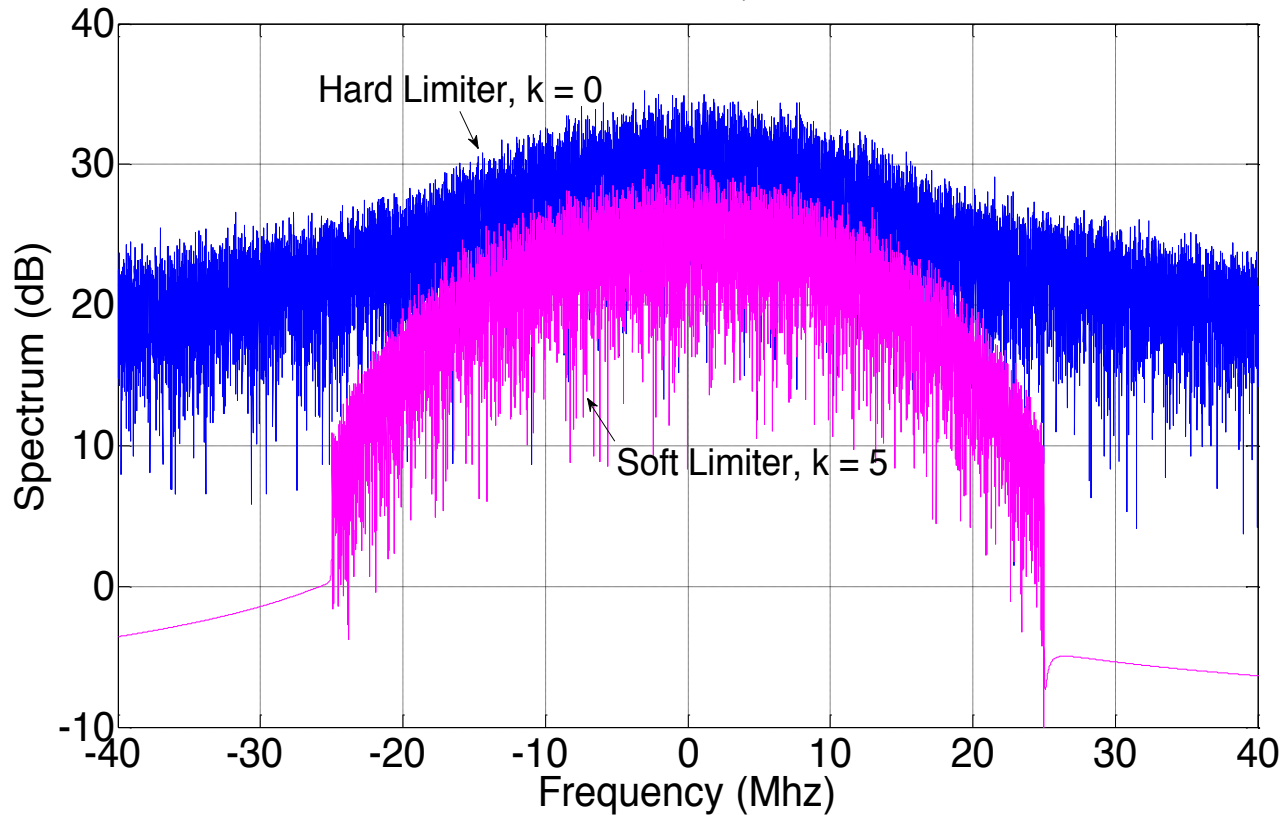
Purely Noisy signals

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Spectrum

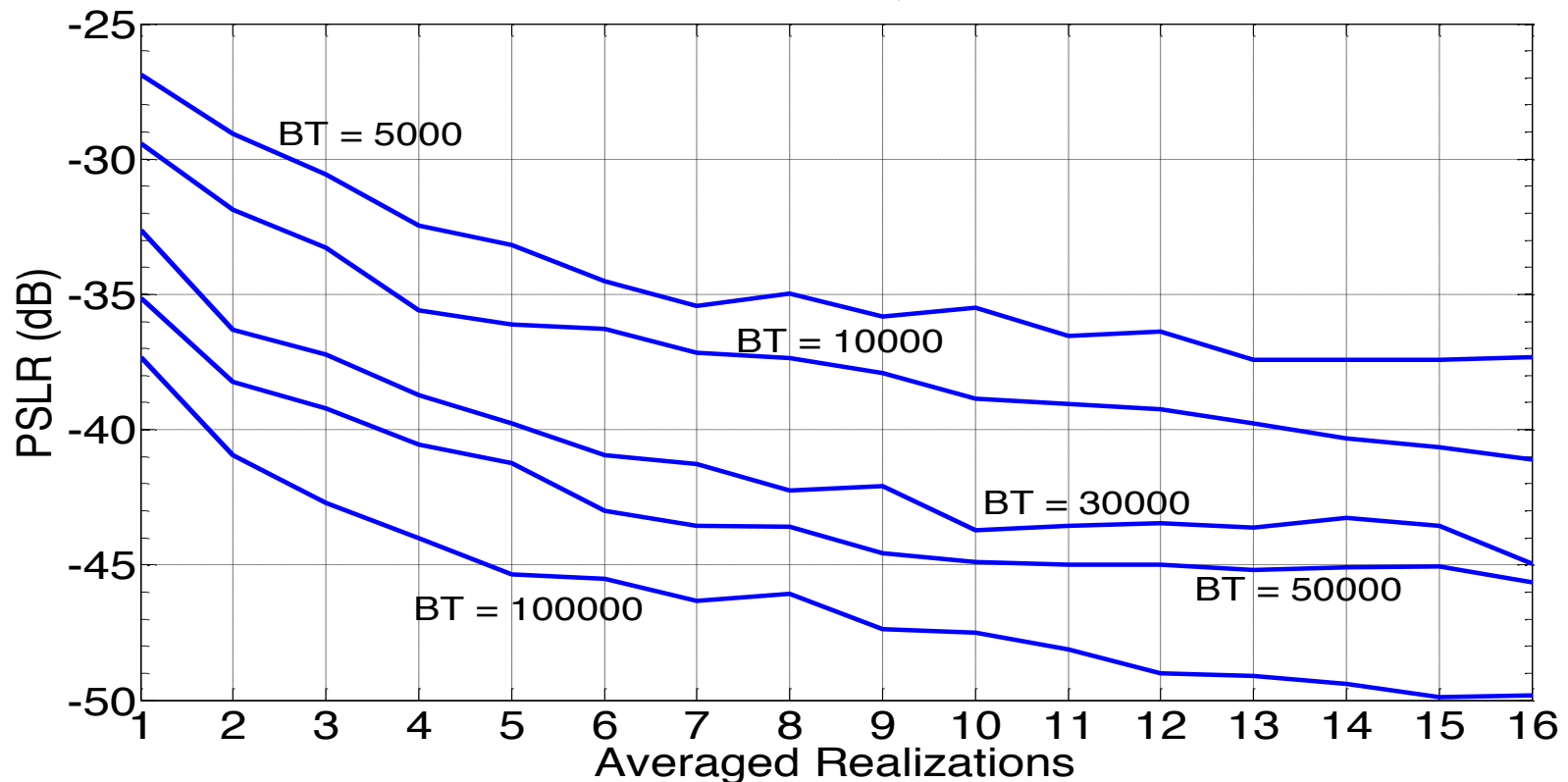
$B = 50 \text{ MHz}$, $T = 200 \mu\text{s}$, $BT = 10000$



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

Coherent average of ACFs to improve PSLR:

$B = 50 \text{ MHz}$, $k = 1$



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



Purely Noisy signals

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Advantages

Unpredictability

- Good LPID properties –

**Unlimited number
of orthogonal
signals**

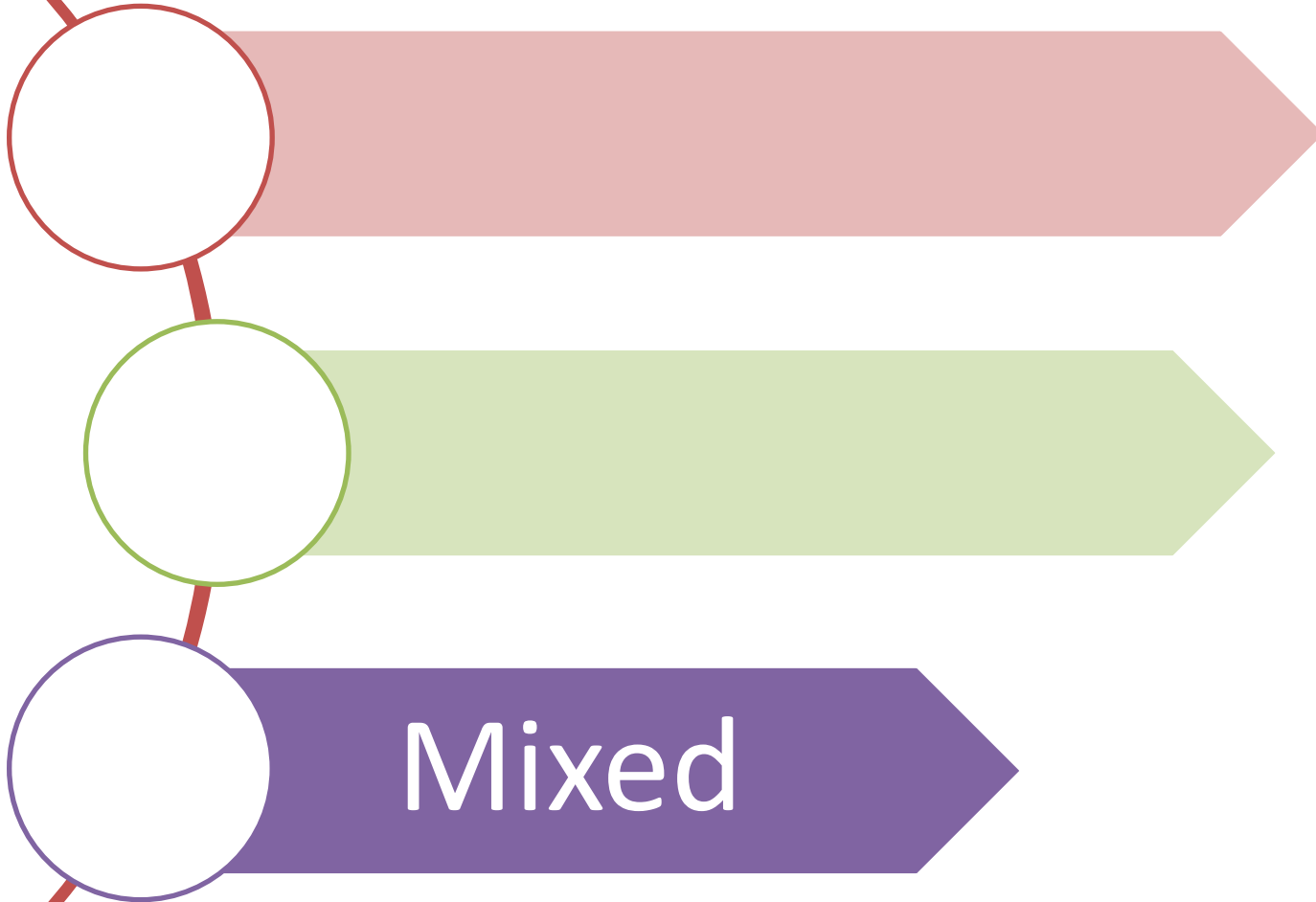
Disadvantages

Low PSLR

Frequency tails

- If hard limited samples –

GENERATION OF DIGITAL WAVEFORMS



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

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

Advanced Pulse Compression Noise [Govoni]

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

Semi Deterministic

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

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

Advanced Pulse Compression Noise [Govoni]

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

Semi Deterministic

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

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

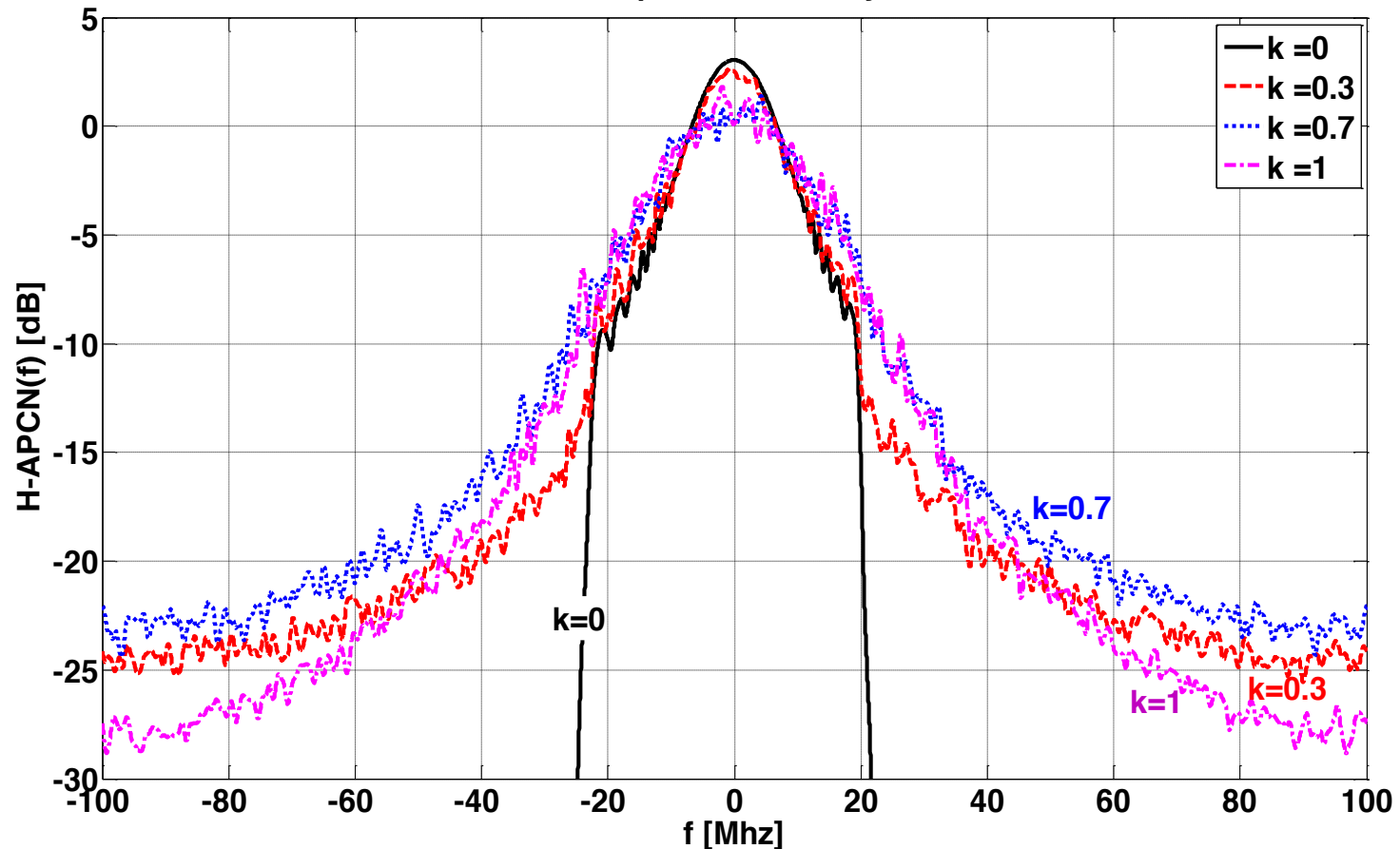
Advanced Pulse Compression Noise [Govoni]

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

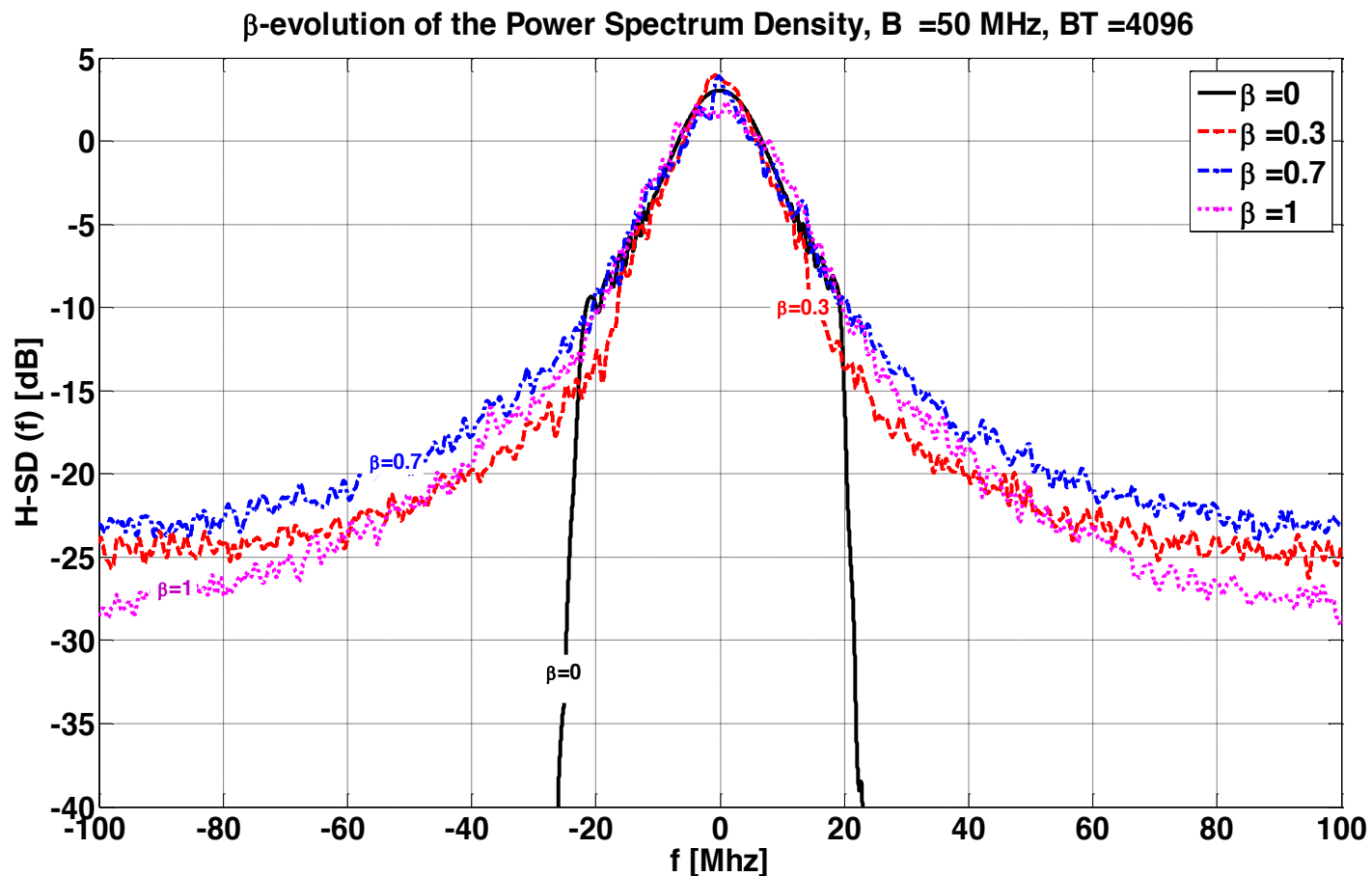
Semi Deterministic

The H-APCN power spectrum

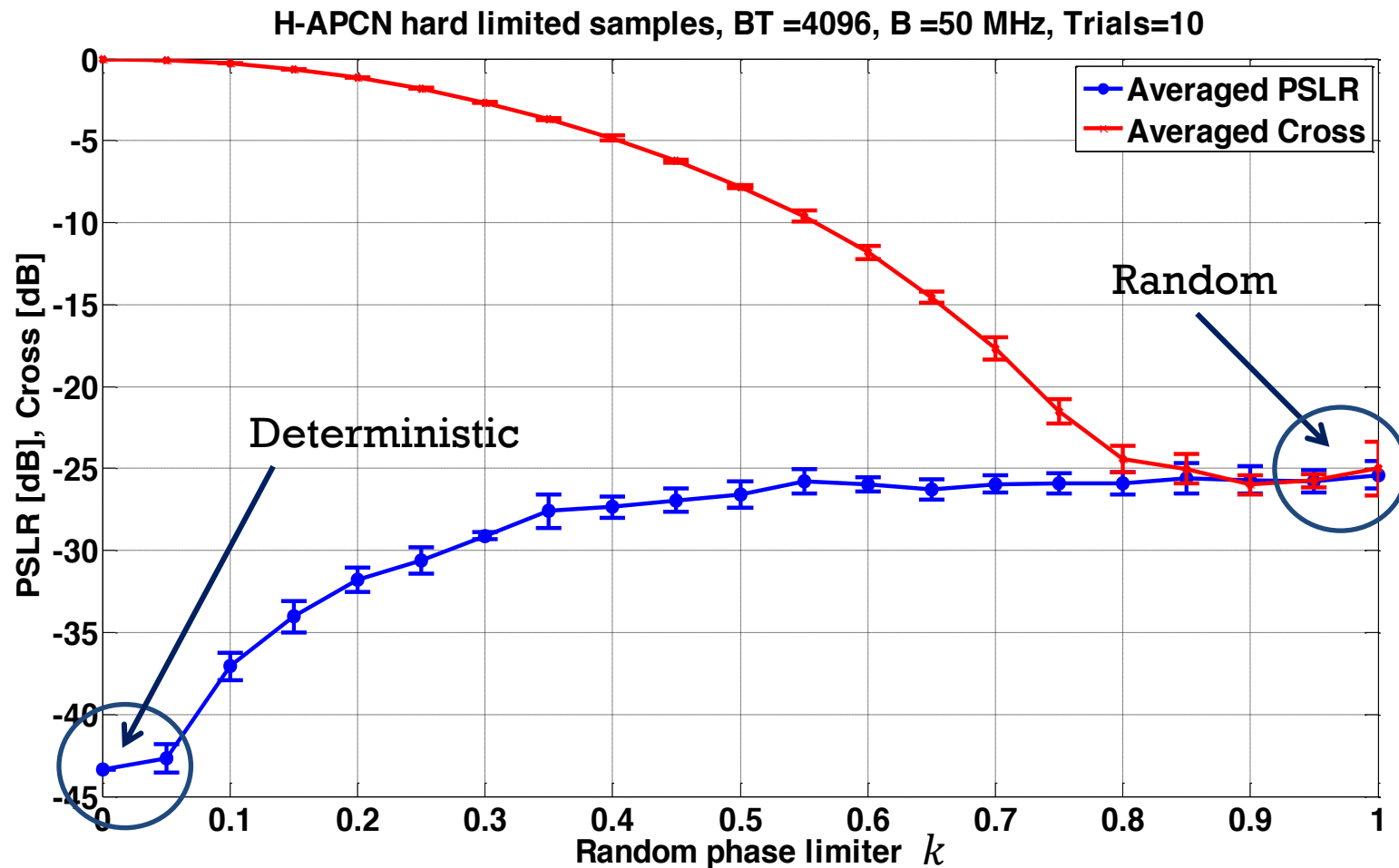
k-evolution of the Power Spectrum Density, $B = 50$ MHz, $BT = 4096$



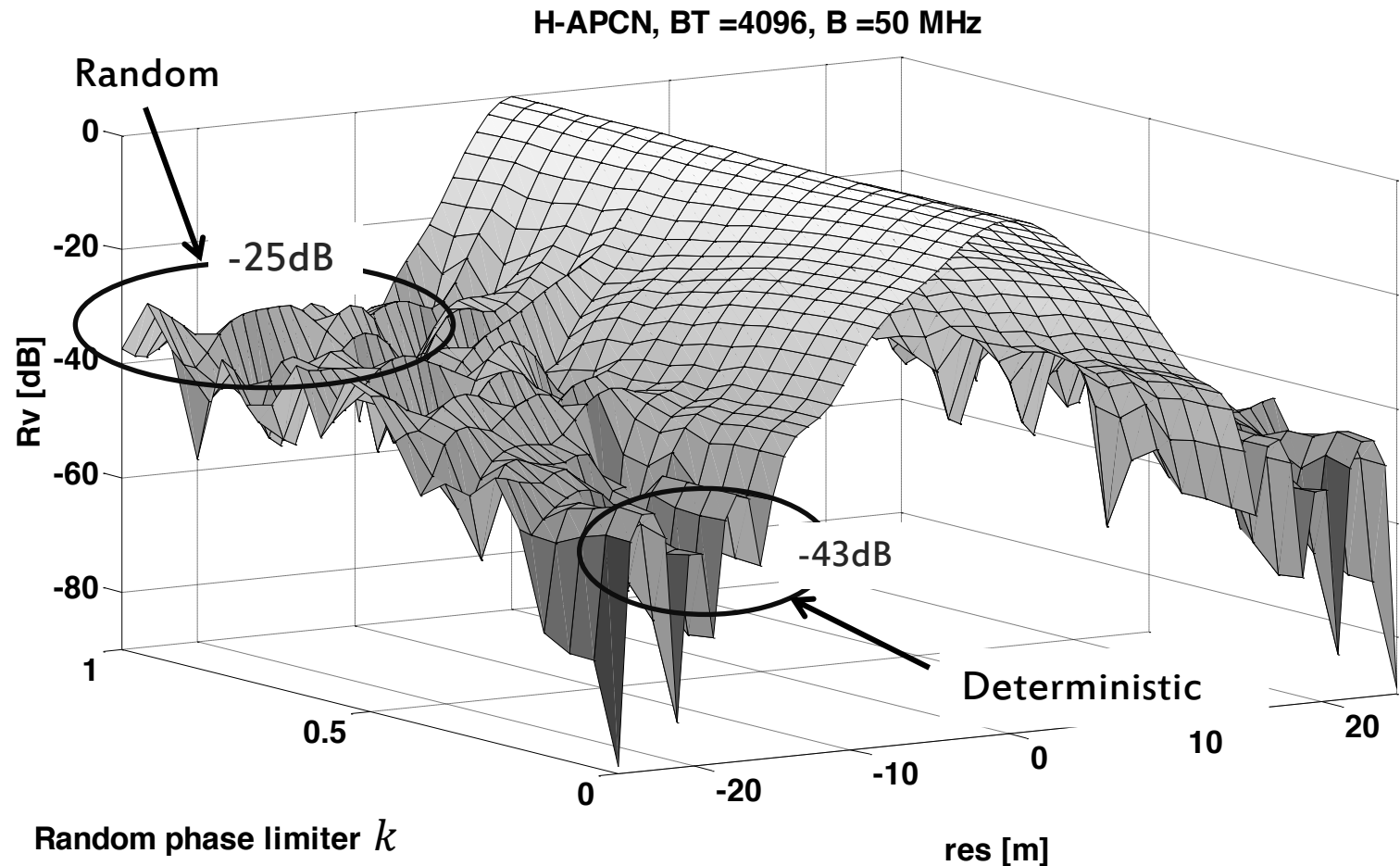
The H-SD power spectrum



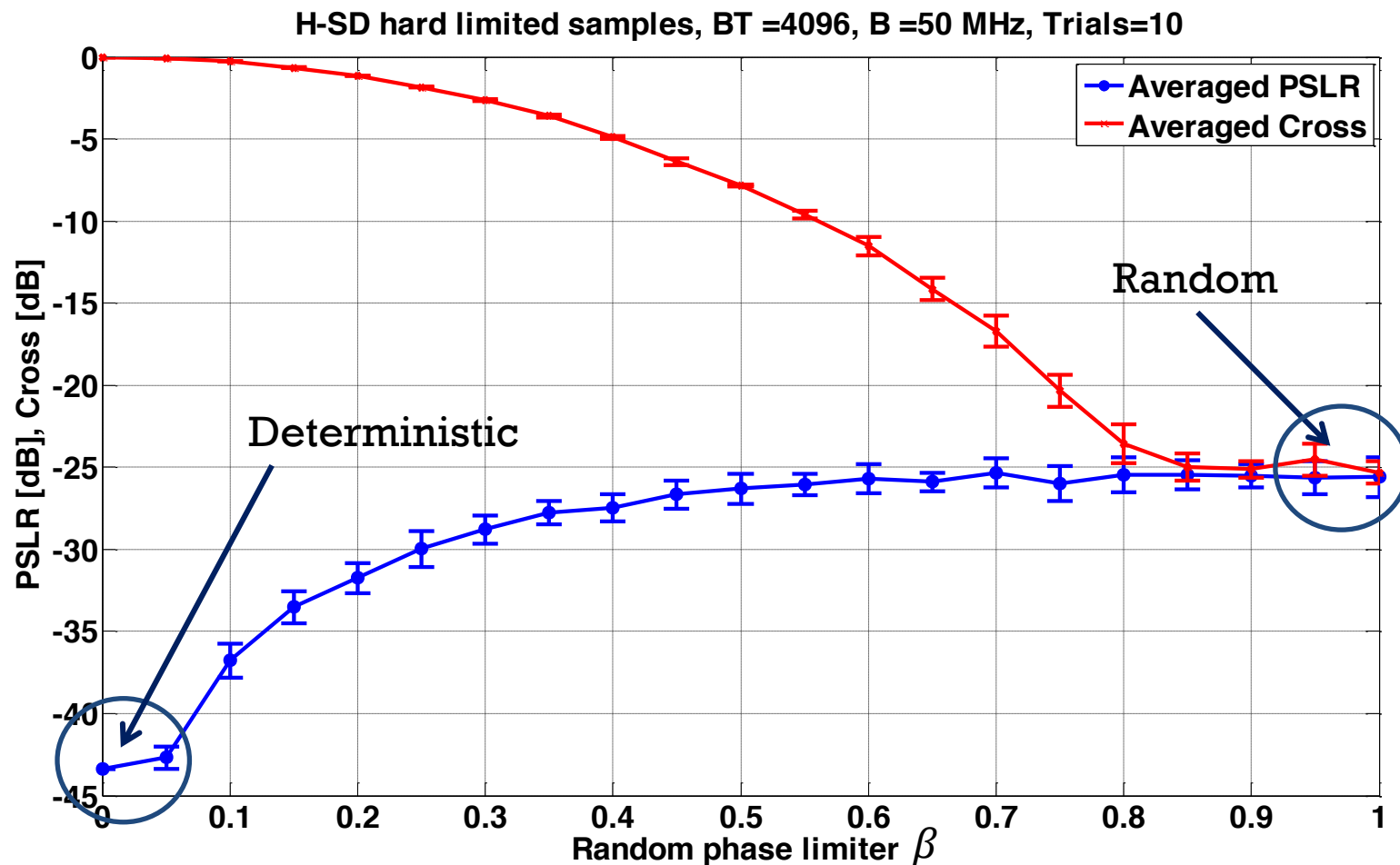
PSLR vs. random phase limiter



ACF vs. random phase limiter

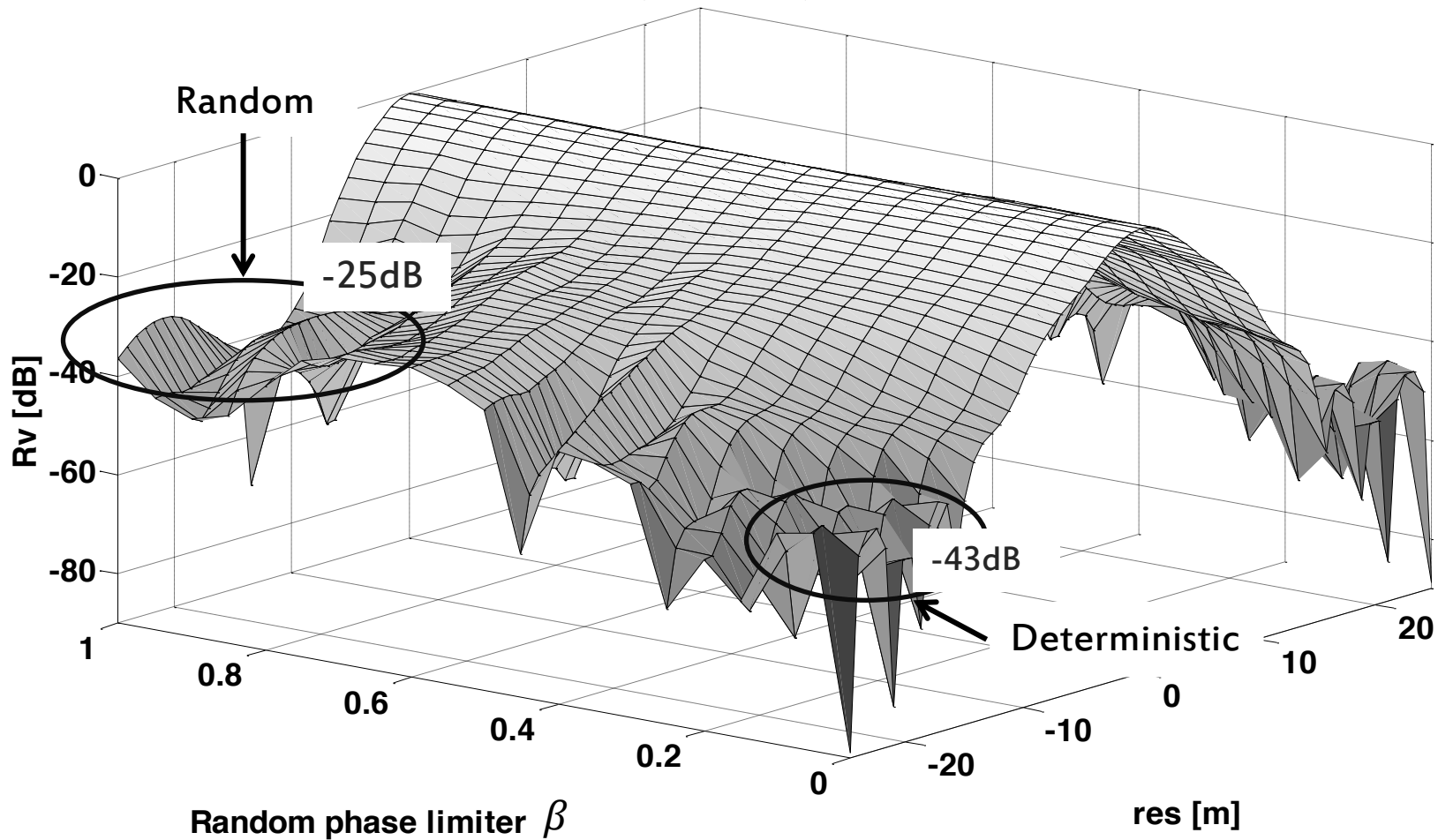


PSLR vs. random phase limiter



ACF vs. random phase limiter

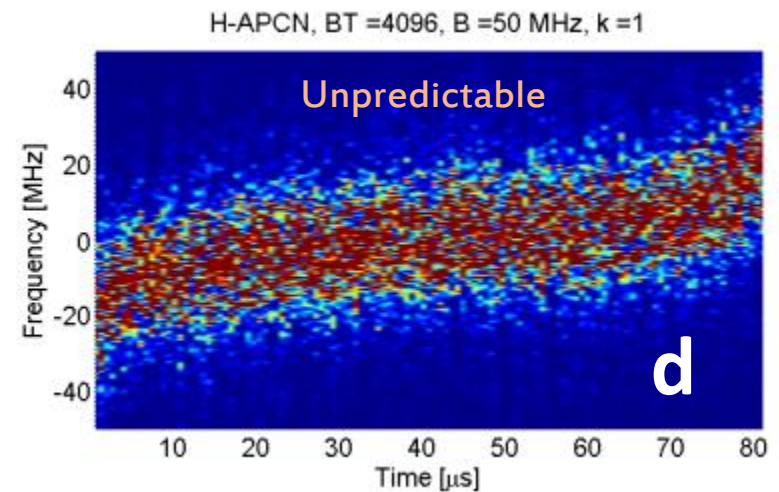
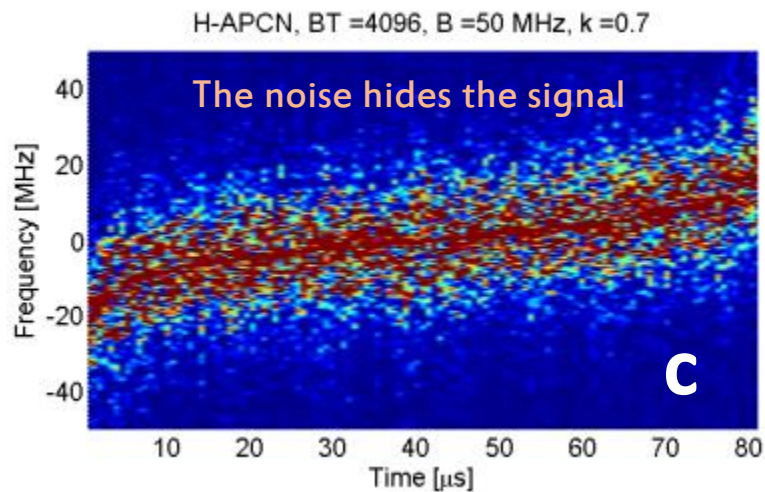
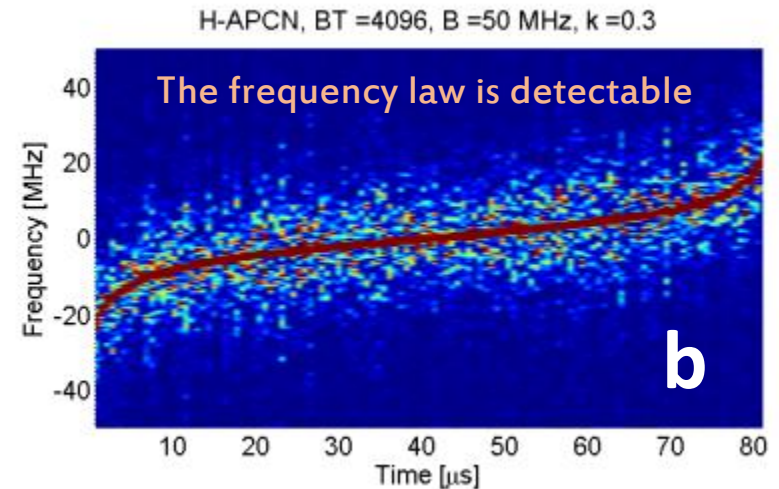
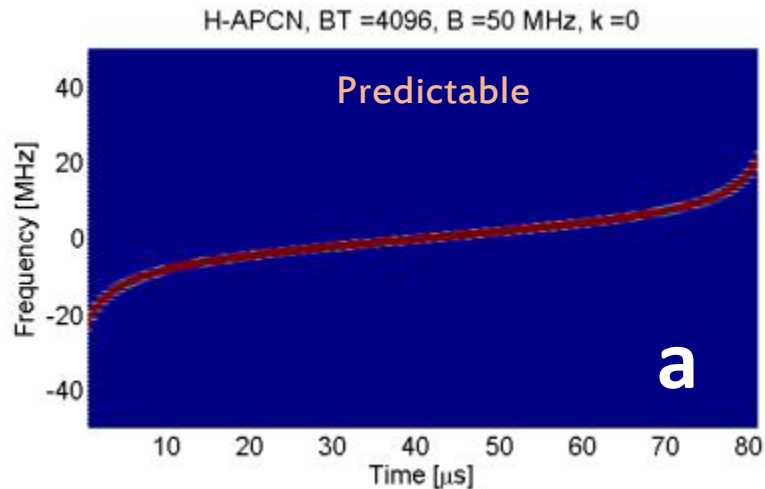
H-SD, BT =4096, B =50 MHz



Mixed signals

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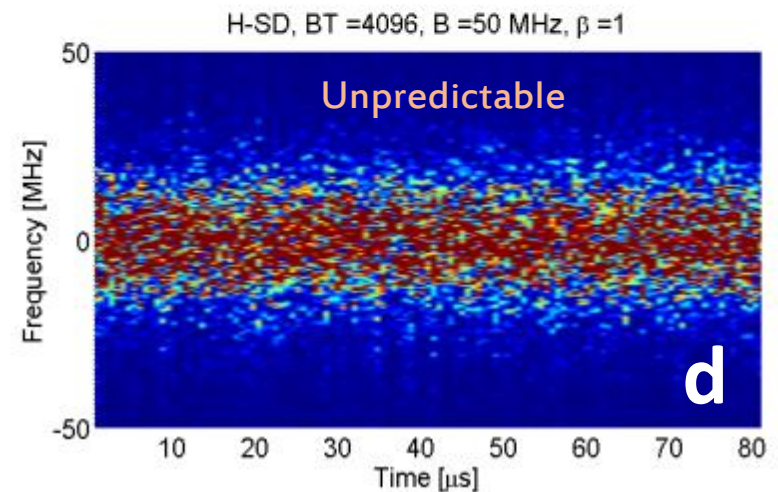
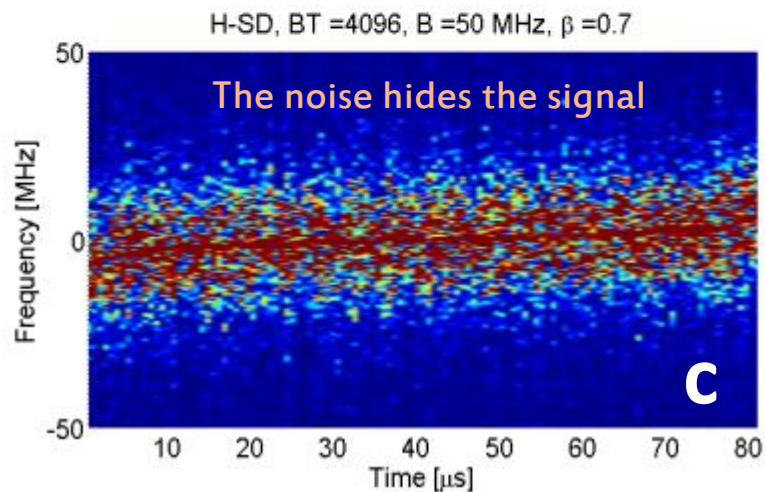
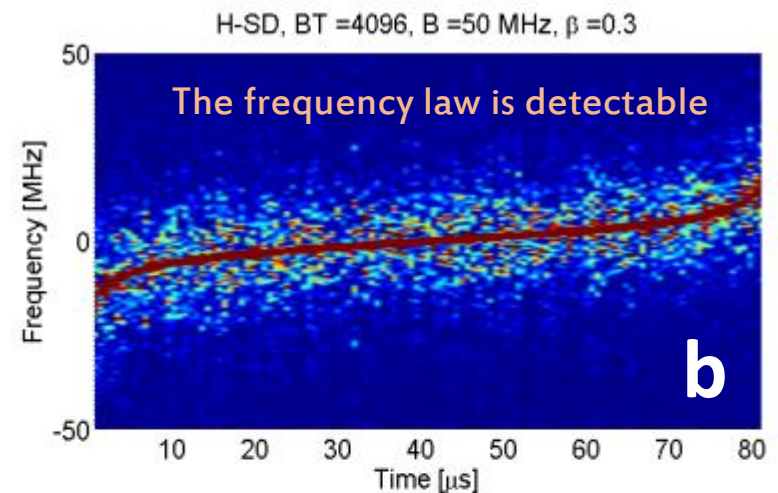
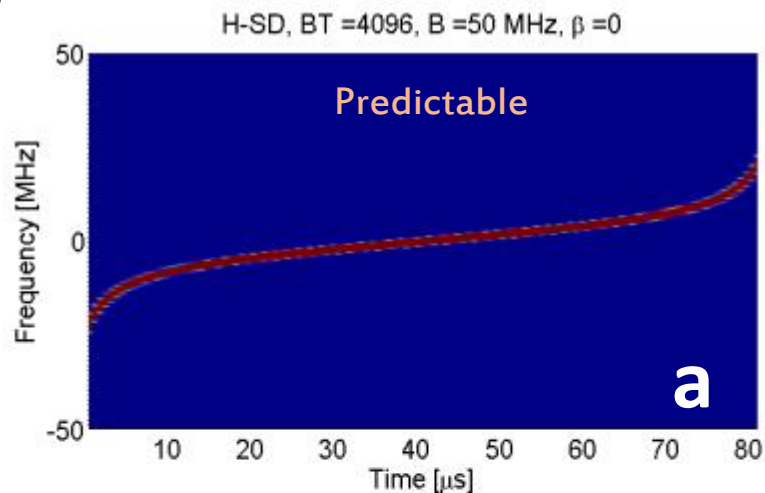
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Mixed signals

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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:

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

MIR satisfies the following properties:

1. $\rho_n > 0$ structured signal
2. $\rho_n = 0$ if $S(\omega) = cost$ (i.e. purely random)

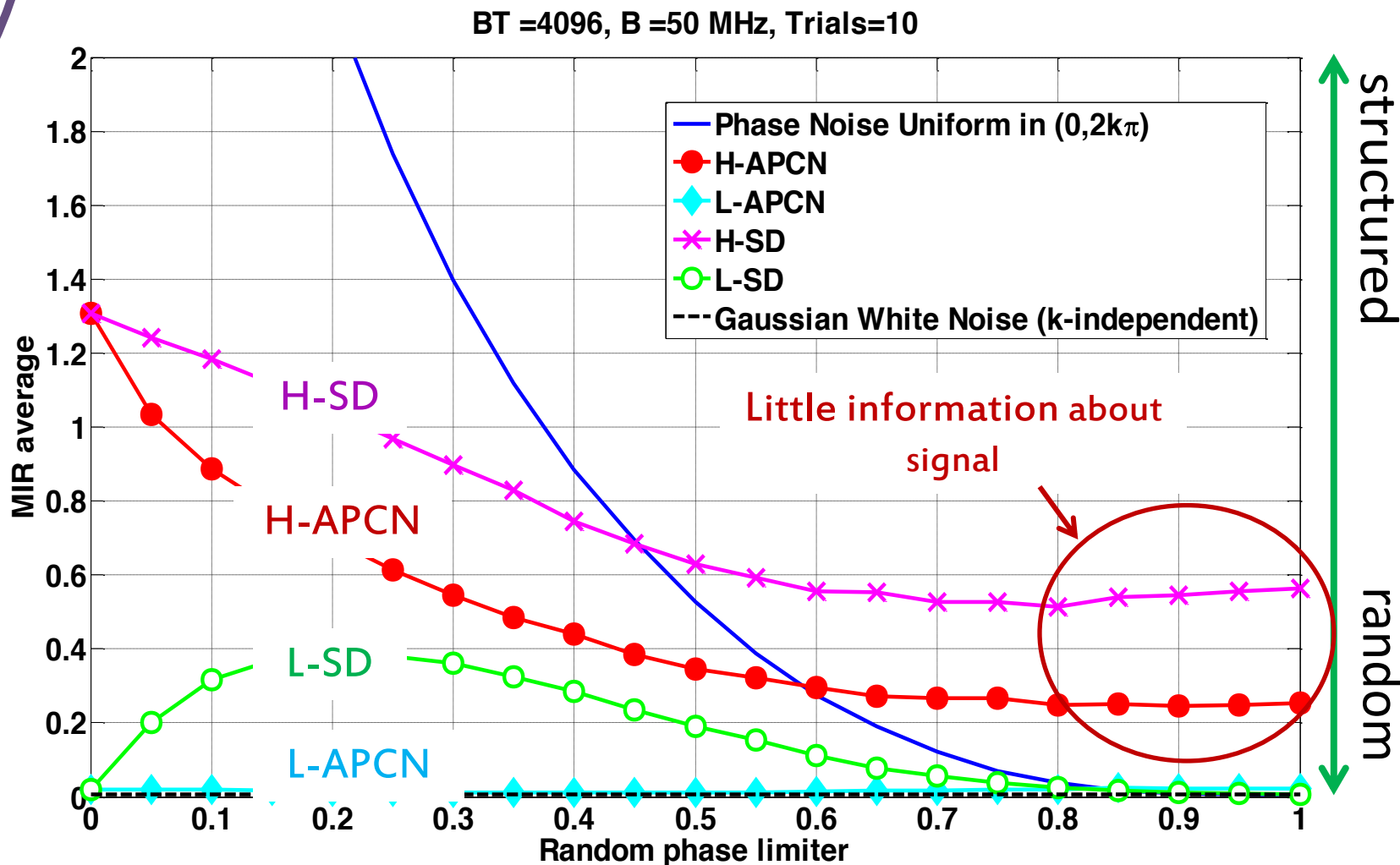


The concept of MIR can be extended to
complex processes [Nesser, Wei Xiong, Picinbono]

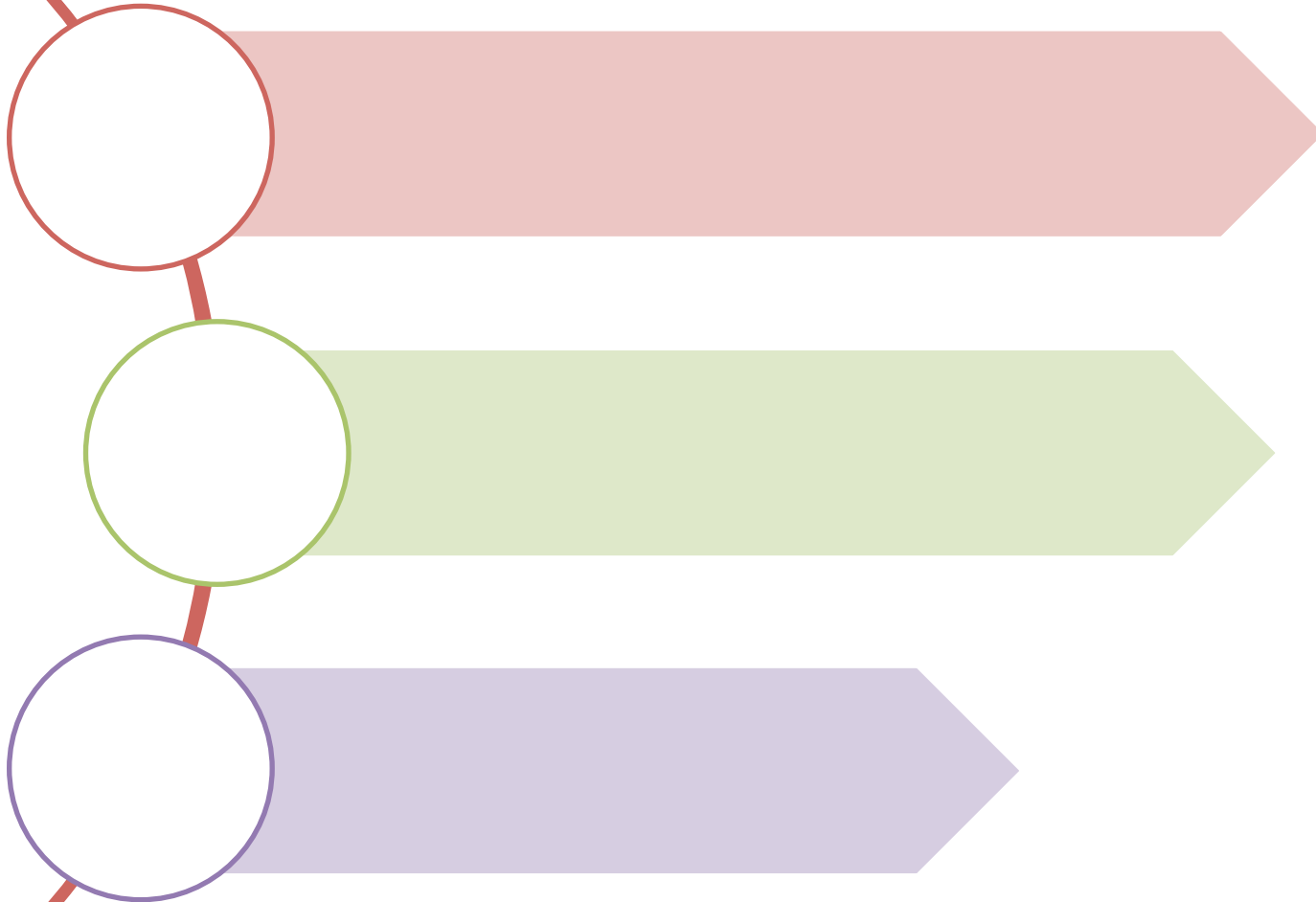
Mixed signals

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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!