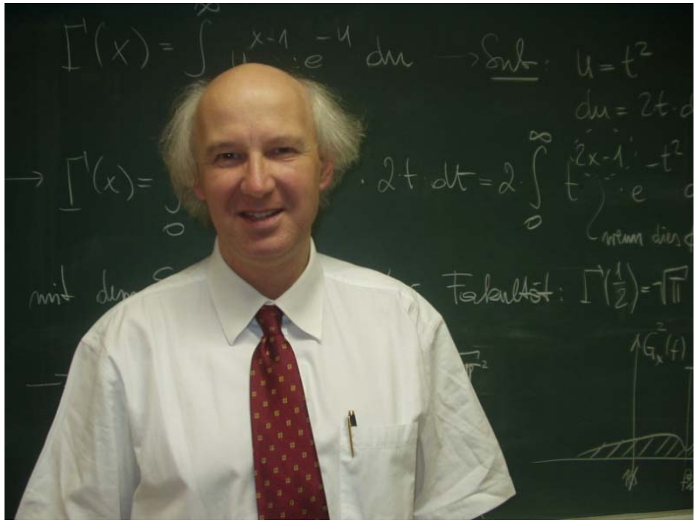
The Nature of Robust and Reliable Communications:

Theory and Applications



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HOCHFREQUENZTECHNIK

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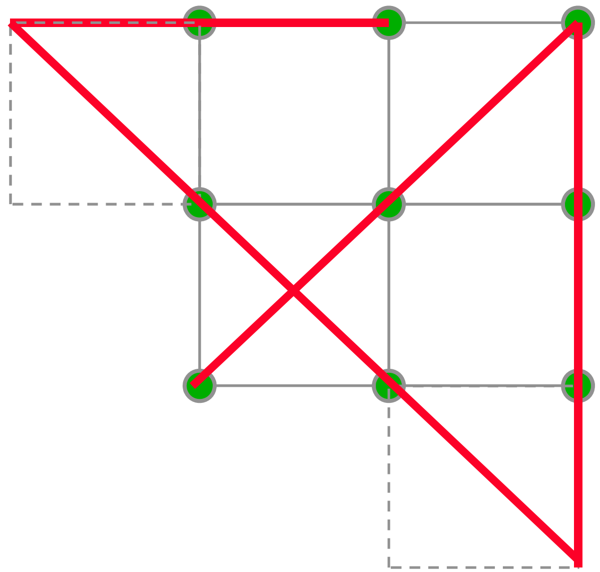
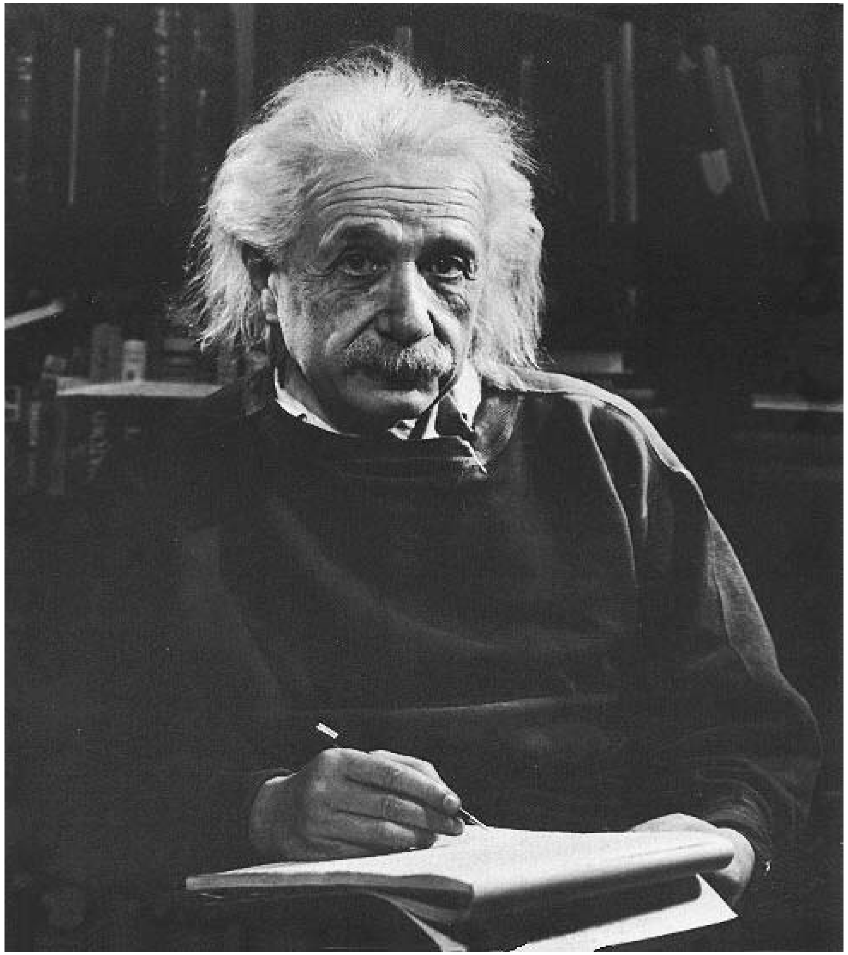
Robust and Reliable Communications needs an Open Mind !

Connect the points in one strike with not more than four lines

Solution:



What counts



Imagination is more than knowledge.

$$\mathbf{E = mc^2}$$

Albert Einstein (1879-1955)

Changes and Challenges in Communications

(1) Globalization
(2) Tendency to open the telecom market
(3) Harmonization for a world standard
(4) Rapid growth of mobile users
(5) Bandwidth hungry services

Requirements for Future Technical Communications

(1) Mobile multi-user schemes [**wireless** terestrial/satellite communication]
  a) Voice
  b) Data
  c) Telemetry

(2) World **coverage**

(3) High degree of **availability**.

(4) **Resources** on demand (billing).

(5) **Flexibility**: Type and quality of service are not known in advance. The killer application is not known.

(6) Cheap and **economic** in use.

⇨ **It is not possible to estimate it precisely enough!**

Expected Interference

Unknown interference everywhere and always due to the rapid growth of mobile users, globalization and the tendency to deregulat the telecom market.

(1) Broadband and narrowband interference
(2) Impulsive and permanent interference
(3) Intensional jamming
(4) Combinations of the above types of interferences
(5) High dynamic changes of the above compositions of interference sources

➡ **It is not possible to estimate it know!**

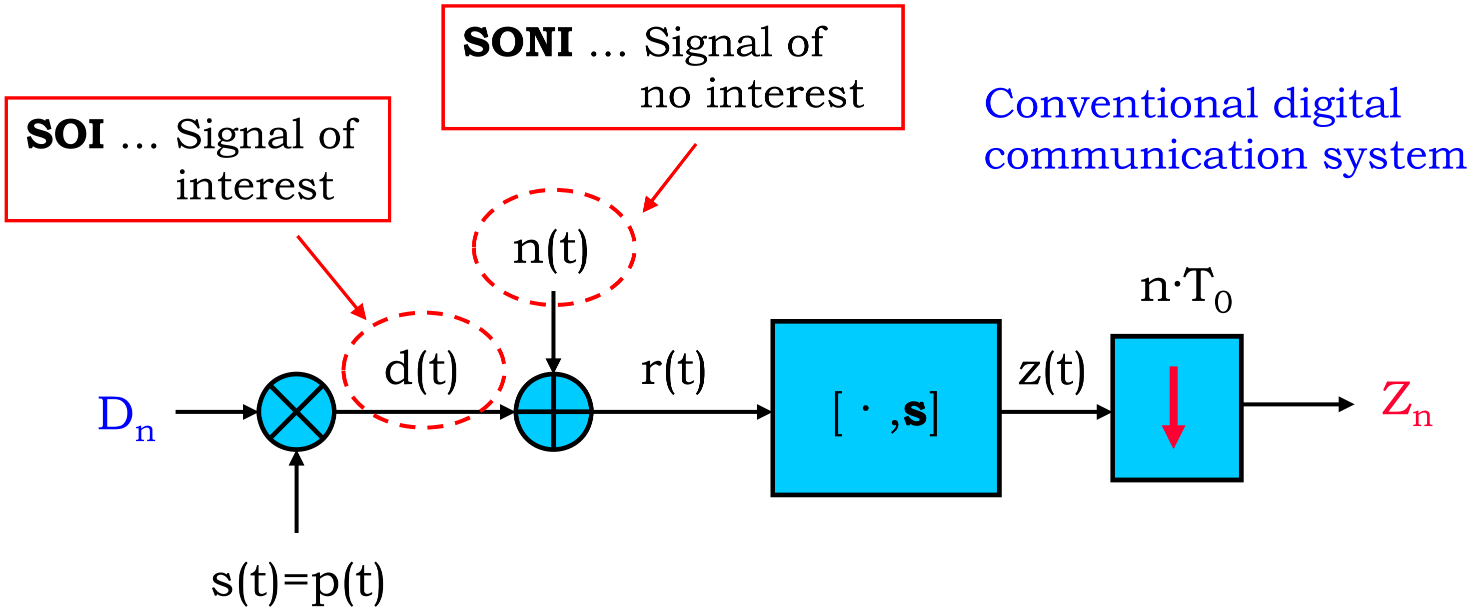
Conventional Digital Communication System

A conventional communication system is used to explain the problem with optimum systems.

Outline:
Bipolar NRZ pulses, AWGN, detector is optimized to AWGN (Matched-Filter/Correlator). The MF maximizes the SNR prior to the decision. High SNR makes the decision more reliable.

Optimum System:

Problem description and definitions:

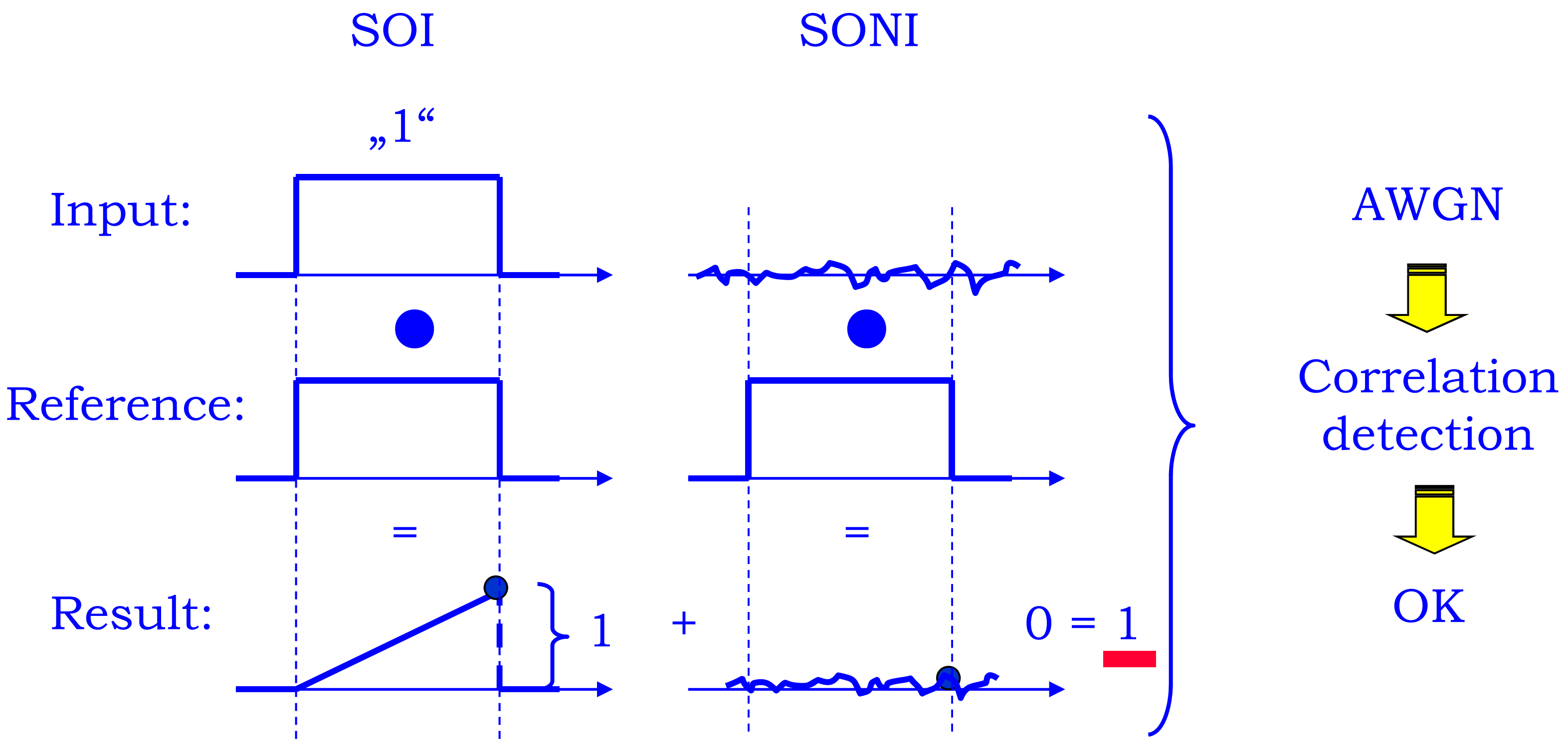


$\mathbf{r} = \mathbf{d} + \mathbf{n} = D_n \cdot \mathbf{s} + \mathbf{n}$ ➡ $Z_n = [\mathbf{r},\mathbf{s}] = D_n \cdot \underbrace{[\mathbf{s},\mathbf{s}]}_{=1} + \underbrace{[\mathbf{n},\mathbf{s}]}_{\to 0}$

Gaussian interference

„Linear property of correlation“

Optimum System:



The **interference reduction effect** is gainded from the **white nature of the interference** itself.

Optimum System:

Now we are looking for the **most harmfull type of interference** that confuses the detector and results in wrong decisions.

Variations:

SONI

$$Z_n = \alpha_1 \cdot D_n \cdot [\mathbf{s},\mathbf{s}] + \alpha_2 \cdot [\mathbf{n},\mathbf{s}] = \alpha_1 \cdot D_n + \alpha_2 \cdot [\mathbf{n},\mathbf{s}]$$

A wrong decision is based on the opposite polarity of the transmitted data bit in the interference term (SONI) and on the condition: $\alpha_2 > \alpha_1$

$$\Rightarrow \quad \mathbf{n} = -D_n \cdot \mathbf{s}$$

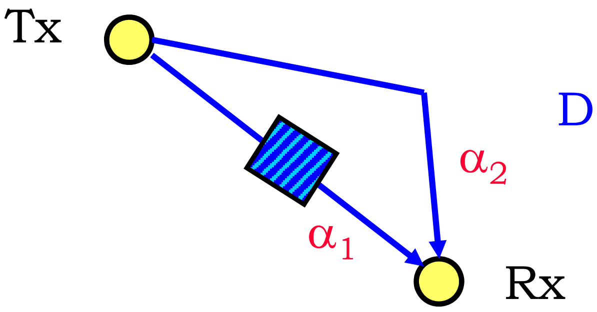
The decision variable for the most harmfull interference is:

$$Z_n = \alpha_1 \cdot D_n + \alpha_2 \cdot \underbrace{[-D_n \cdot \mathbf{s},\mathbf{s}]}_{-D_n} = D_n \cdot (\alpha_1 - \alpha_2)$$

Optimum System:

The most harmfull interference waveform is one which produces an additive component in the decision variable containing the **same information** as the desired waveform.

Physical Interpretation: The worste case occures when the interference presents the detector a signal (SONI) which is a delayed replica of the SOI. That‘s **multipath** interference!



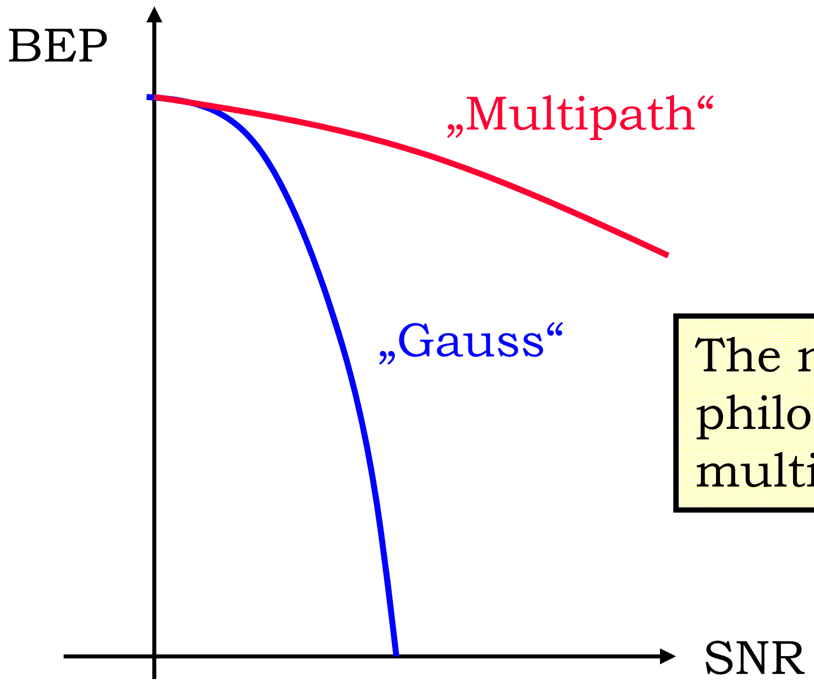
$\alpha_1 < \alpha_2$

Delay large enough for phase canceling

⇒ **„Unresolvable Error“**

Optimum System:

Problem: In a multipath environment the conventional detector (optimized for AWGN) can not distiguish between the SOI and SONI (resolve the multipath components). The BEP raises significantly!



The need of a detection philosophy that resolves the multipath components is obvios.

Optimum System:

Remark:

The bad behavior in a multipath environment is not a great surprise, because the conventional detector (optimized for AWGN) is trained to find the polarity of a DC level and to average out all disturbances. **Disturbances** are treated as interference.

If, like in the multipath case, the detector finds an additional DC level, it considers that as something usefull and make no attempt to reduce it.

The way out of the dilemma

Robust Systems:

Spread-Spectrum Technolgy

The Inventor of Spread-Spectrum Technology

Hedy Lamarr and George Antheil. Photo of Hedy Lamarr courtesy of the Academy of Motion Picture Arts & Sciences. Photo of George Antheil courtesy of the Estate of George Antheil.

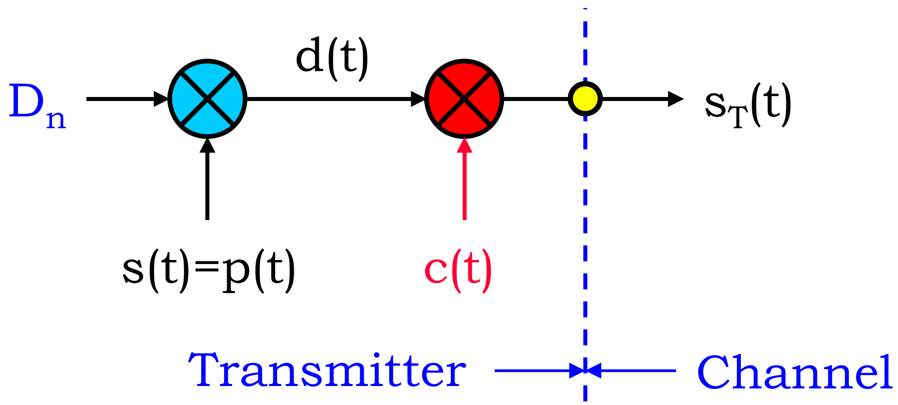
Robust System: Spread-Spectrum Technology

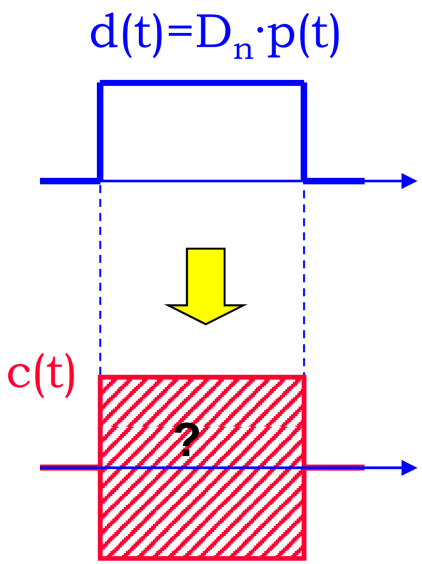
<u>Fact</u>: We have control about the transmitted signal (SOI).

Remember the IR mechanism in AWGN is based on the white nature of the interference itself and the averaging operation corresponding to the integration. E.g. „chopping behavior“.

How can that mechanism be realized for multipath interference ?

Preparing the SOI

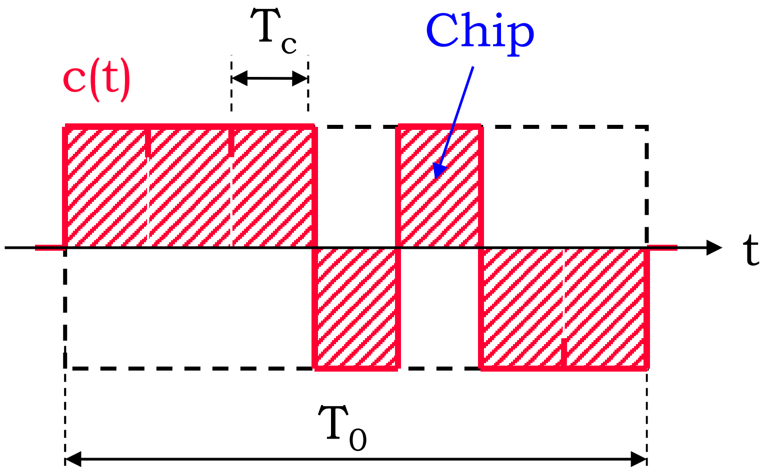




Robust System: Spread-Spectrum Technology

Spread-Spectrum Signal: c(t).

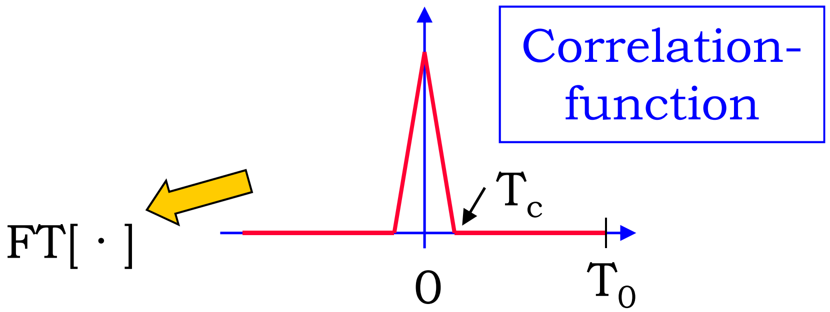
L=7 … Number of chips/symbol



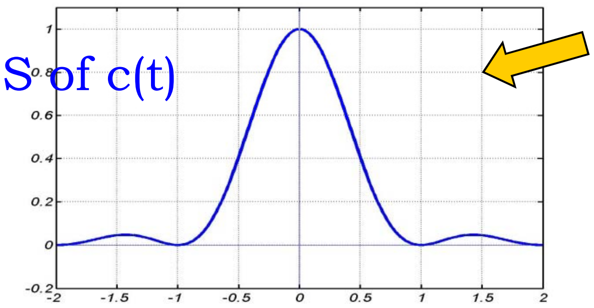
→ DC-less

$$\int_0^{T_0} c(t)\cdot dt = 0 \quad \text{… OK}$$

→ Synchronization possible

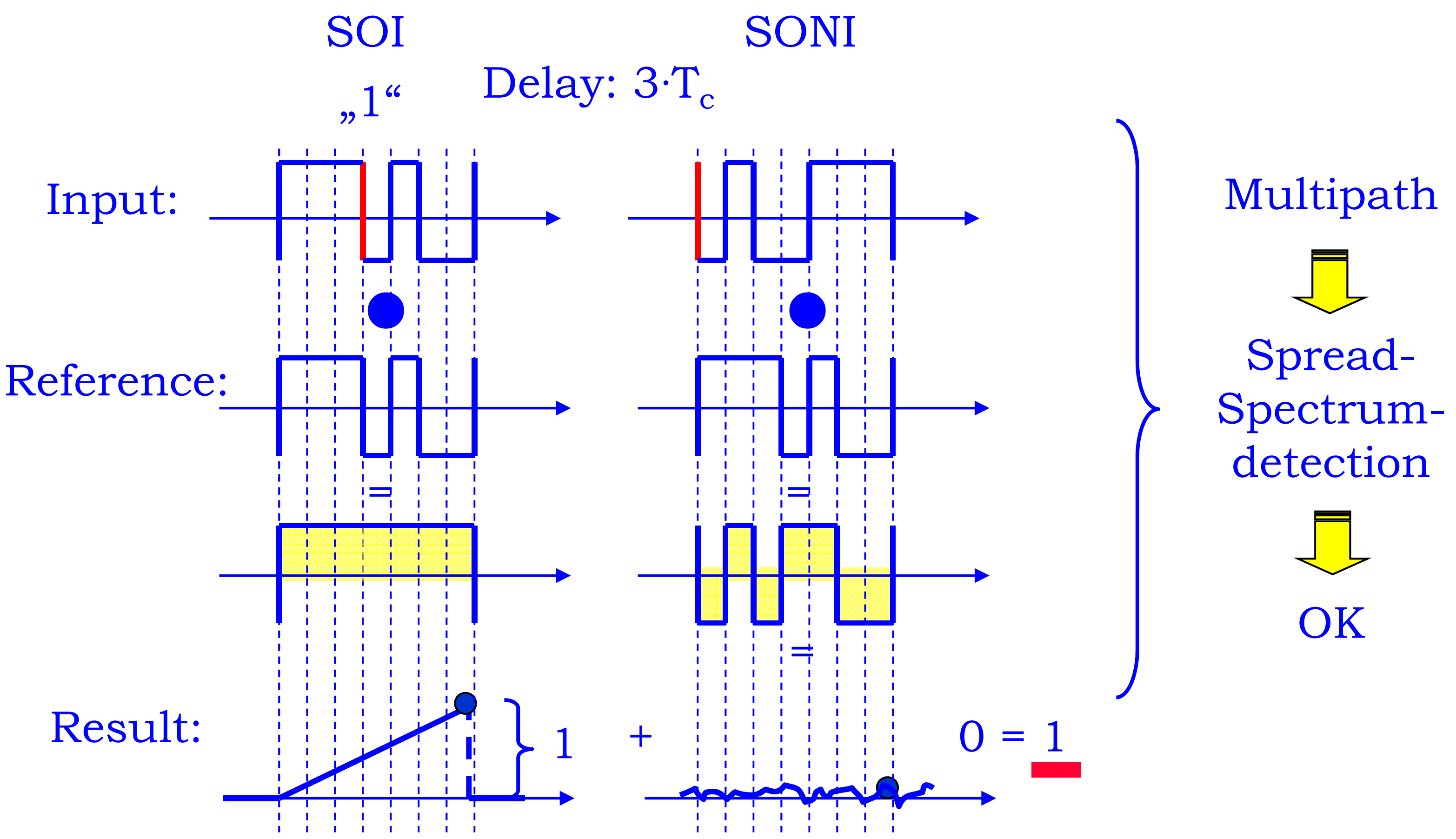


PDS of c(t)



→ Generalized IR-processing corrsponding to „chopping“-operation.

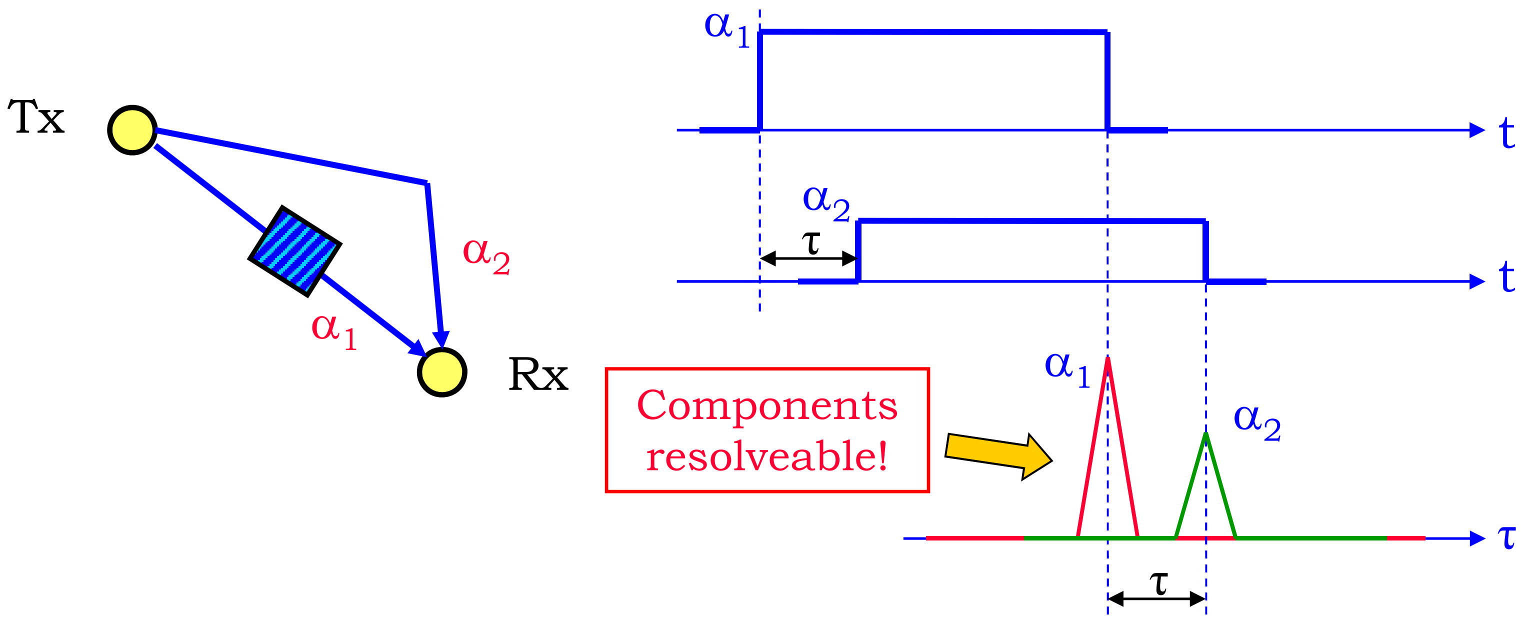
Robust System: Spread-Spectrum Technology (MRR)



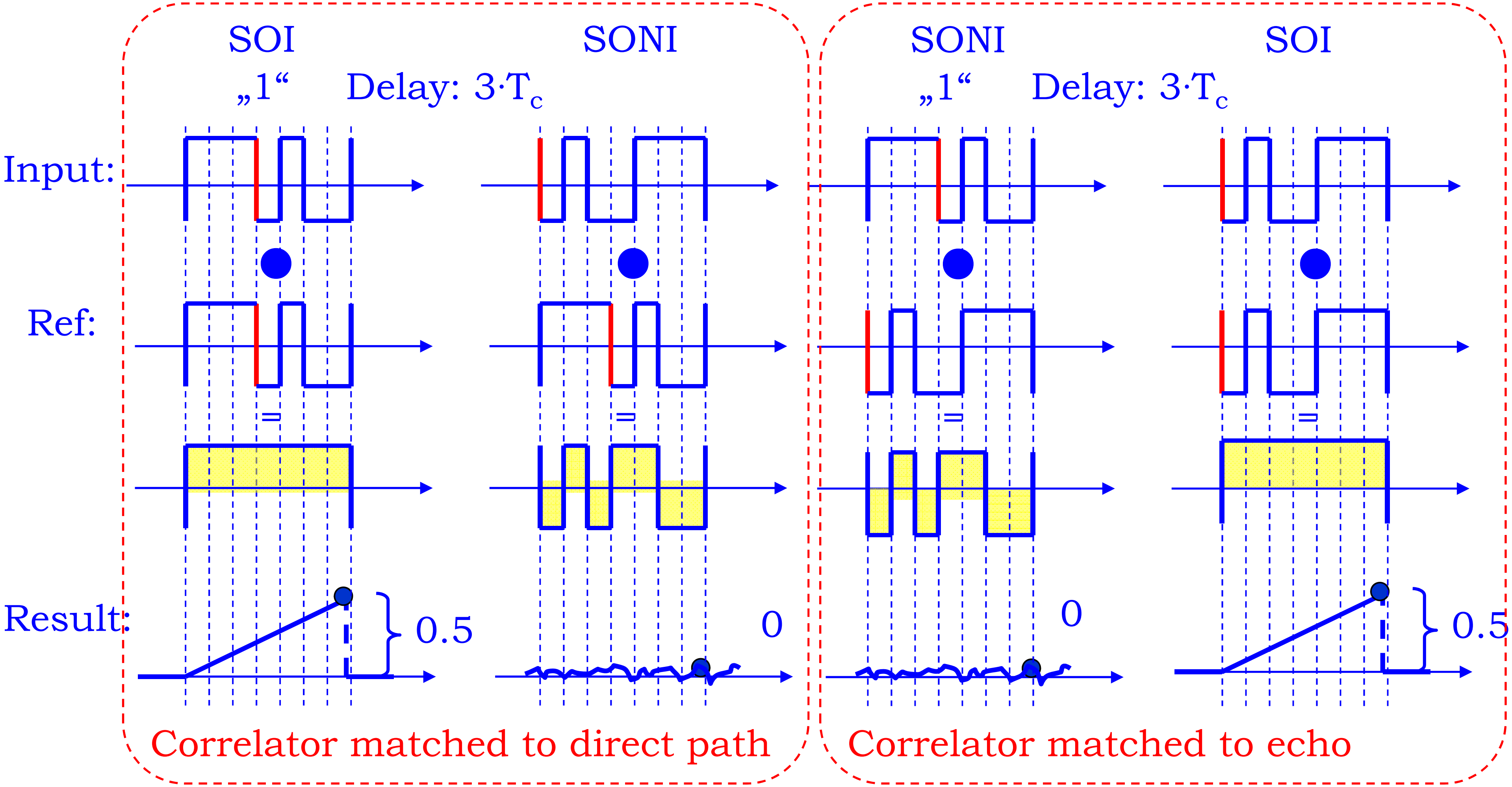
The **interference reduction effect** is gainded from the **white nature of the spread-spectrum signal**.

Robust System: Spread-Spectrum Technology

„Resolveability of the multipath components due to the 2-valued Auto-Correlation-Function“



Robust System: Spread-Spectrum Technology (RAKE)



$$Z_n = Z_1 + Z_2 = [\mathbf{s}_1, \mathbf{s}_1] + [\mathbf{s}_1, \mathbf{n}_1] + [\mathbf{s}_2, \mathbf{n}_2] + [\mathbf{s}_2, \mathbf{s}_2] = 0.5 + 0 + 0 + 0.5 = \underline{1}$$

Robust System: Spread-Spectrum Technology

Remarks to the spread-spectrum philosophy

The spread-spectrum concept is a **generalization** of the „**whitening procedure**“ for <u>any</u> interfering waveform.

We have **learned from nature** to prepare our communication system to make it more robust and reliable against unpredictable kinds of interfering waveforms.

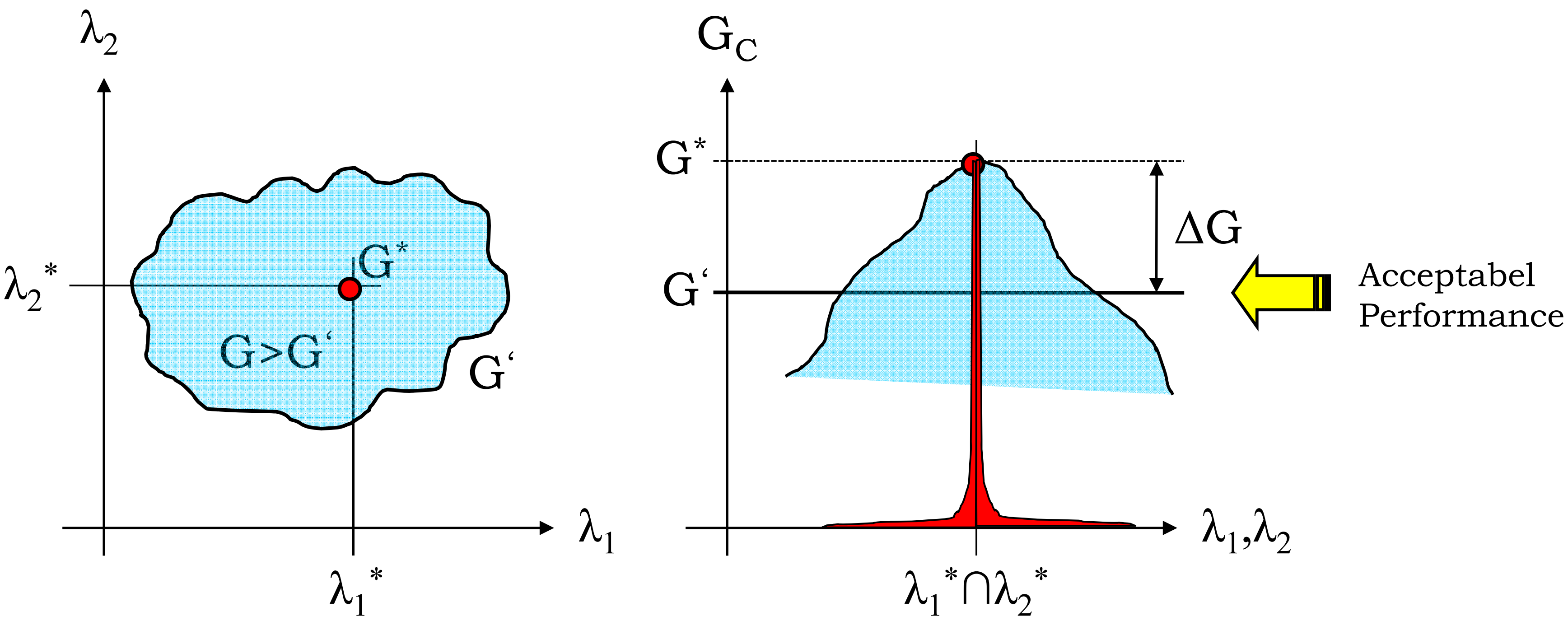
„PN-property“

Sloopy speaking: Before integration the SOI has no zero-crossings and the SONI has many zero-crossings, that garantees:

[**s**,**s**] approaches 1 and [**n**,**s**] approaches 0

General Remarks on Optimum Systems and Robust Systems

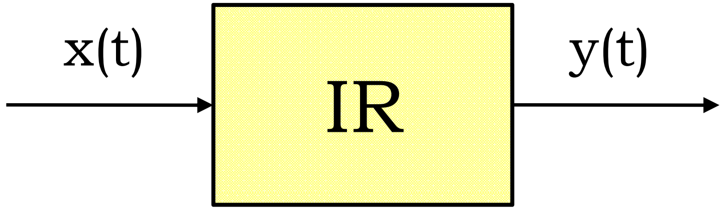
Robustness and Reliability



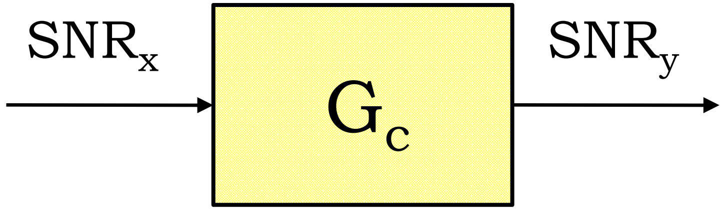
$G \rightarrow G^{*} = \max\{G\}$ … Optimum

$G \rightarrow G \geq G'$ … **Robust**

Interference Reduction (IR)



IR-Processor



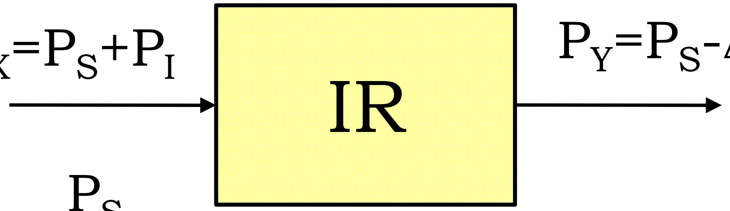
$$G_c = \frac{SNR_y}{SNR_x} > 1$$ ... Conversion-Gain

Robust and Reliability

S … SOI
I …. SONI

IR-Processor

$P_X = P_S + P_I$



$P_Y = P_S - \Delta P_S + P_I - \Delta P_I$

$$SNR_X = \frac{P_S}{P_I} \qquad SNR_Y = \frac{P_S - \Delta P_S}{P_I - \Delta P_I}$$

$\Delta P_I \equiv P_I$ and $\Delta P_S \ll \Delta P_I$

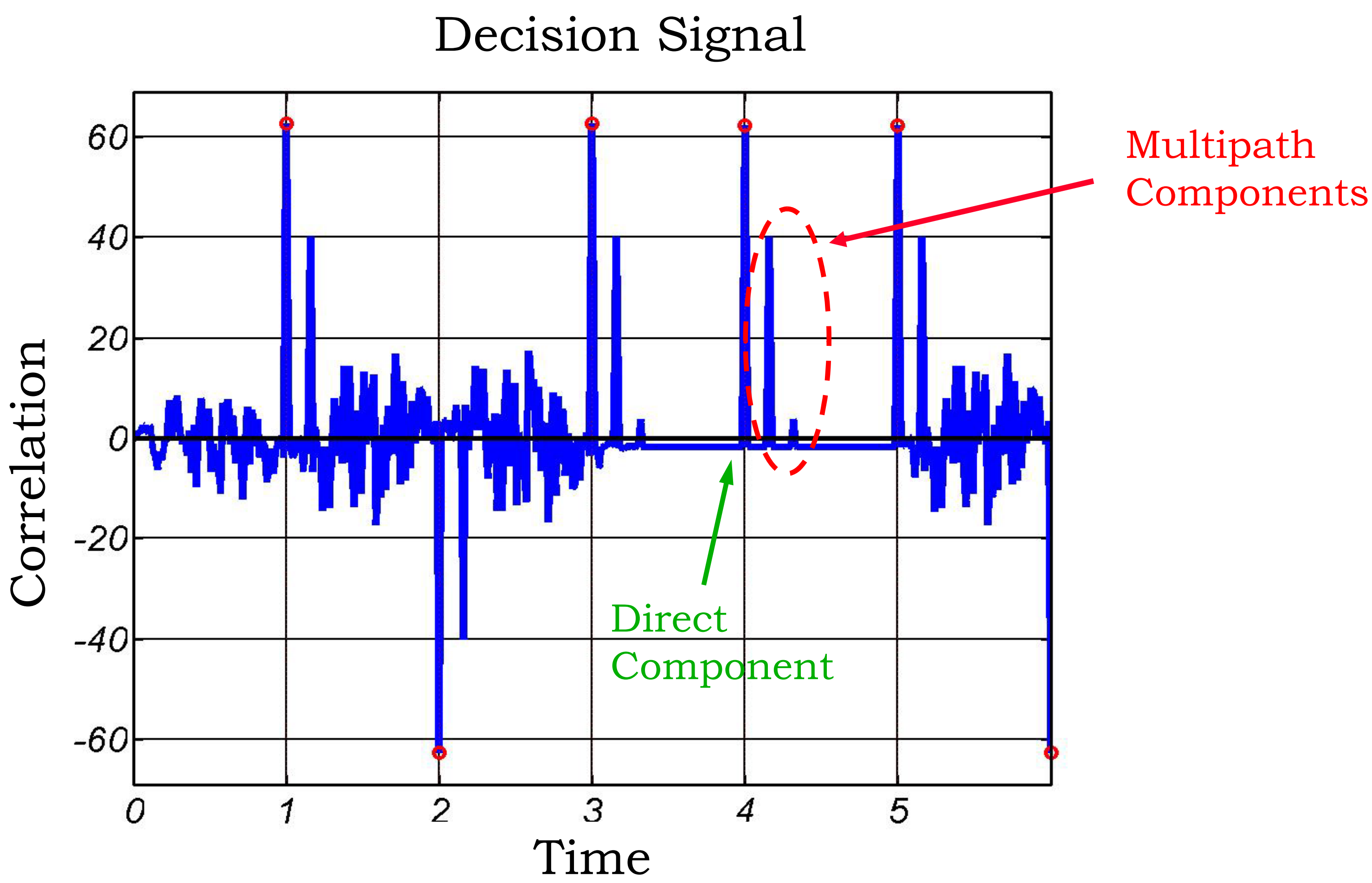
Goal: Remove the SONI without distorting the SOI.

$\Delta P_I \equiv P_I$ …. Interference **Suppression**.

$\Delta P_I \approx P_I$ …. Interference **Reduction**.

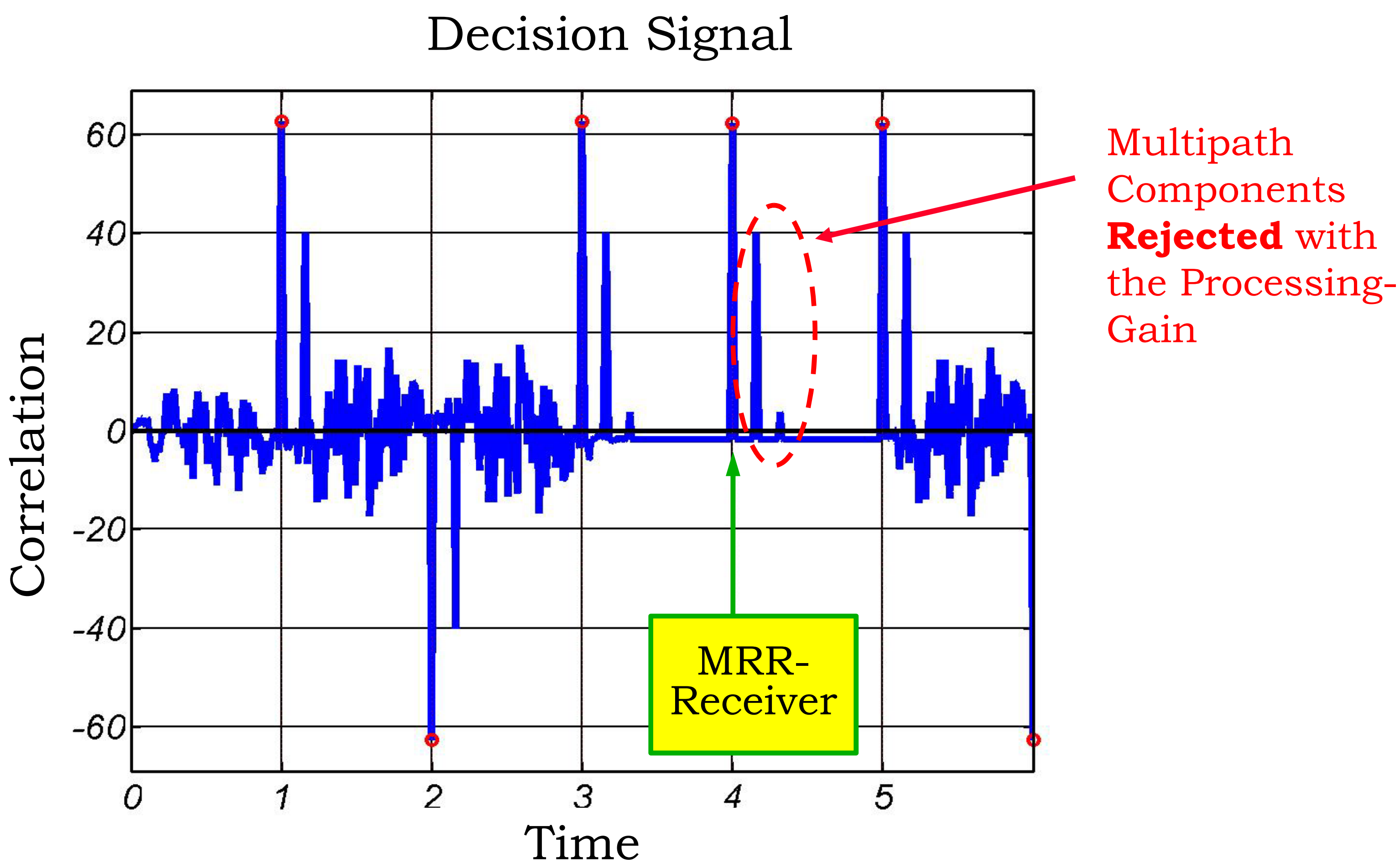
Usefull Properties for Future Applications

Spread-Spectrum: Estimating the Multipath Profile



Exploiting the pseudo-random property of the spread-spectrum signal.

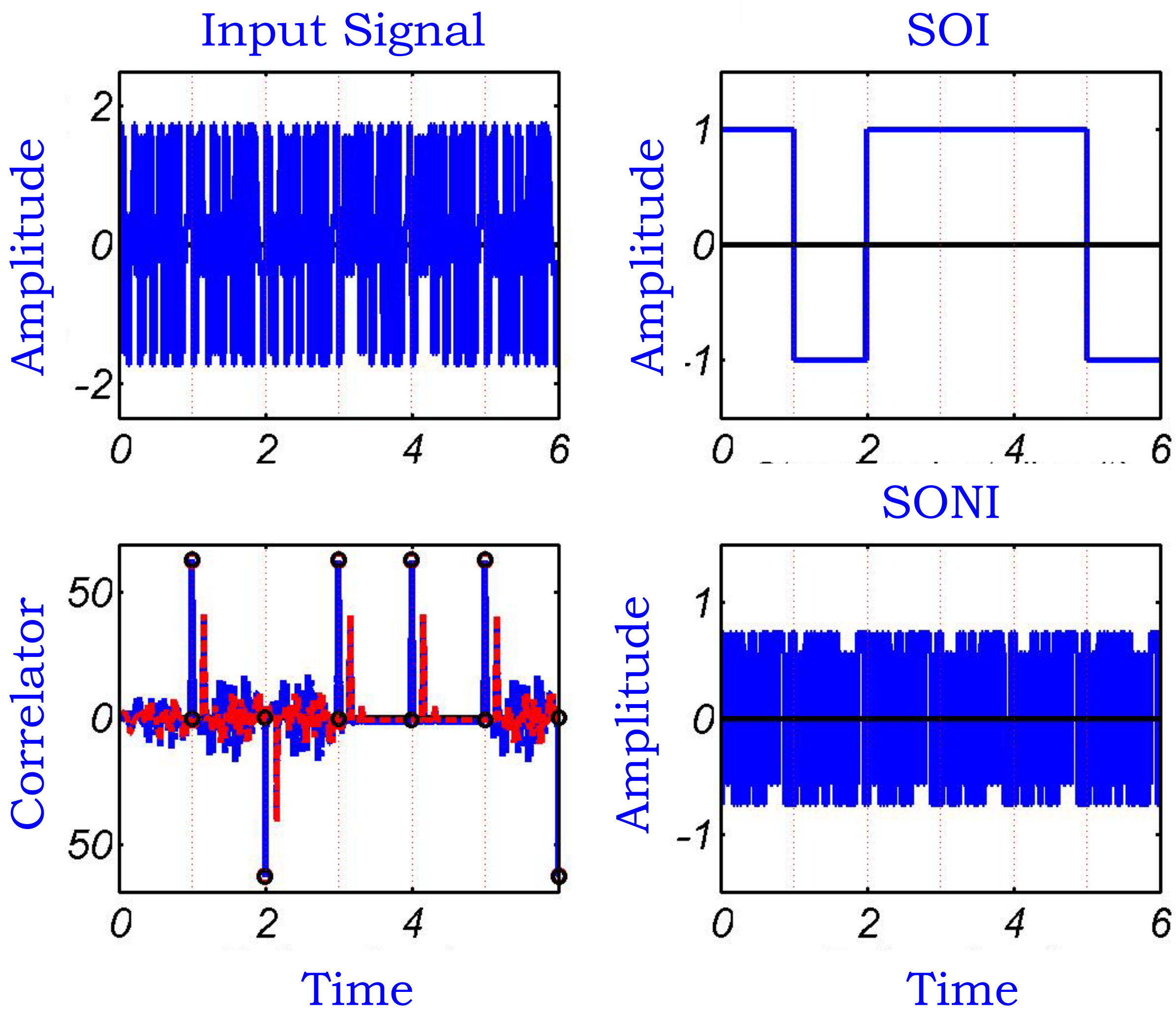
Spread-Spectrum: Multi-Path Rejection Receiver (MRR)



Exploiting the pseudo-random property of the spread-spectrum signal.

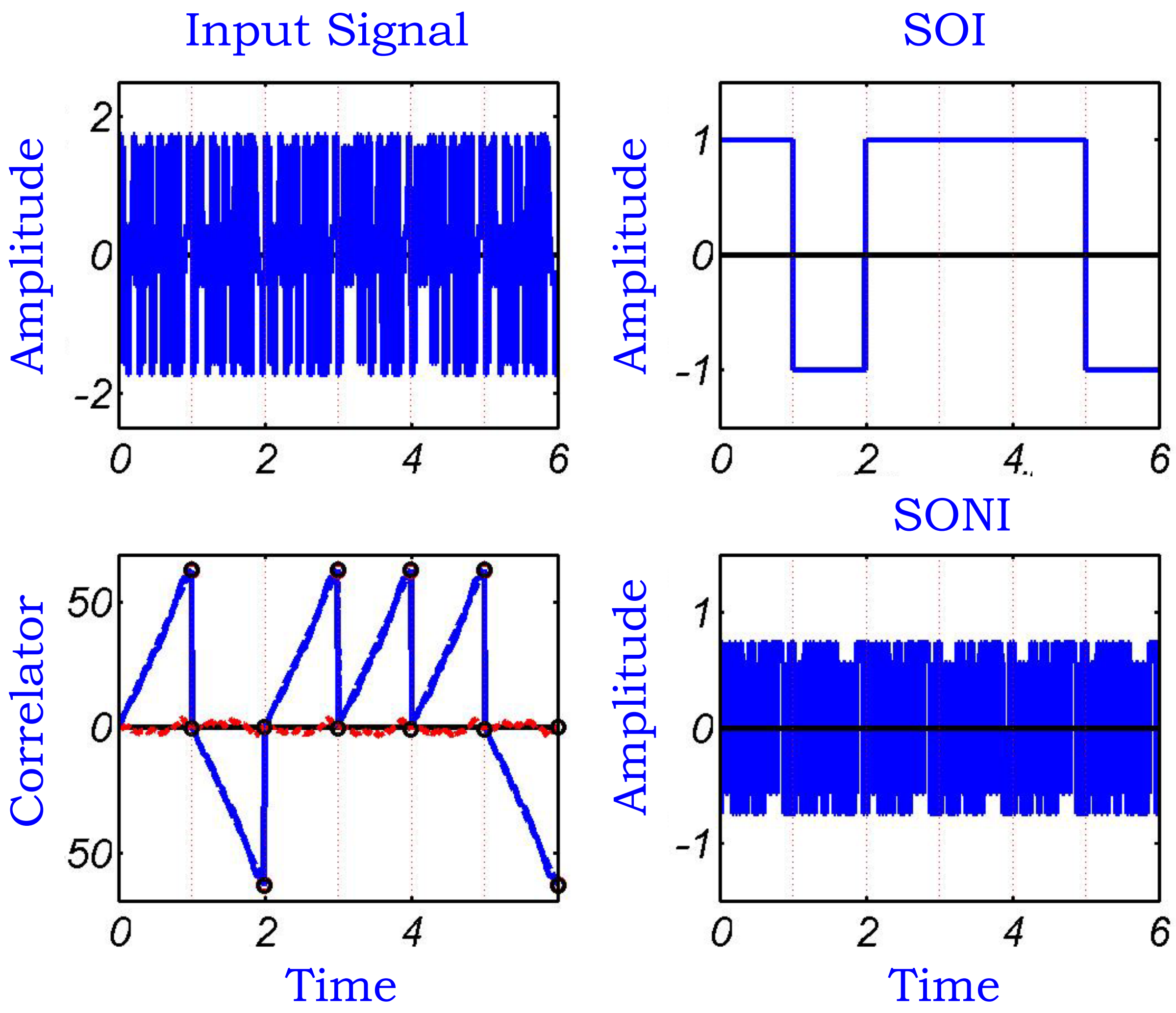
Multipath - MRR

Multipath Rejection Receiver [passive MF]

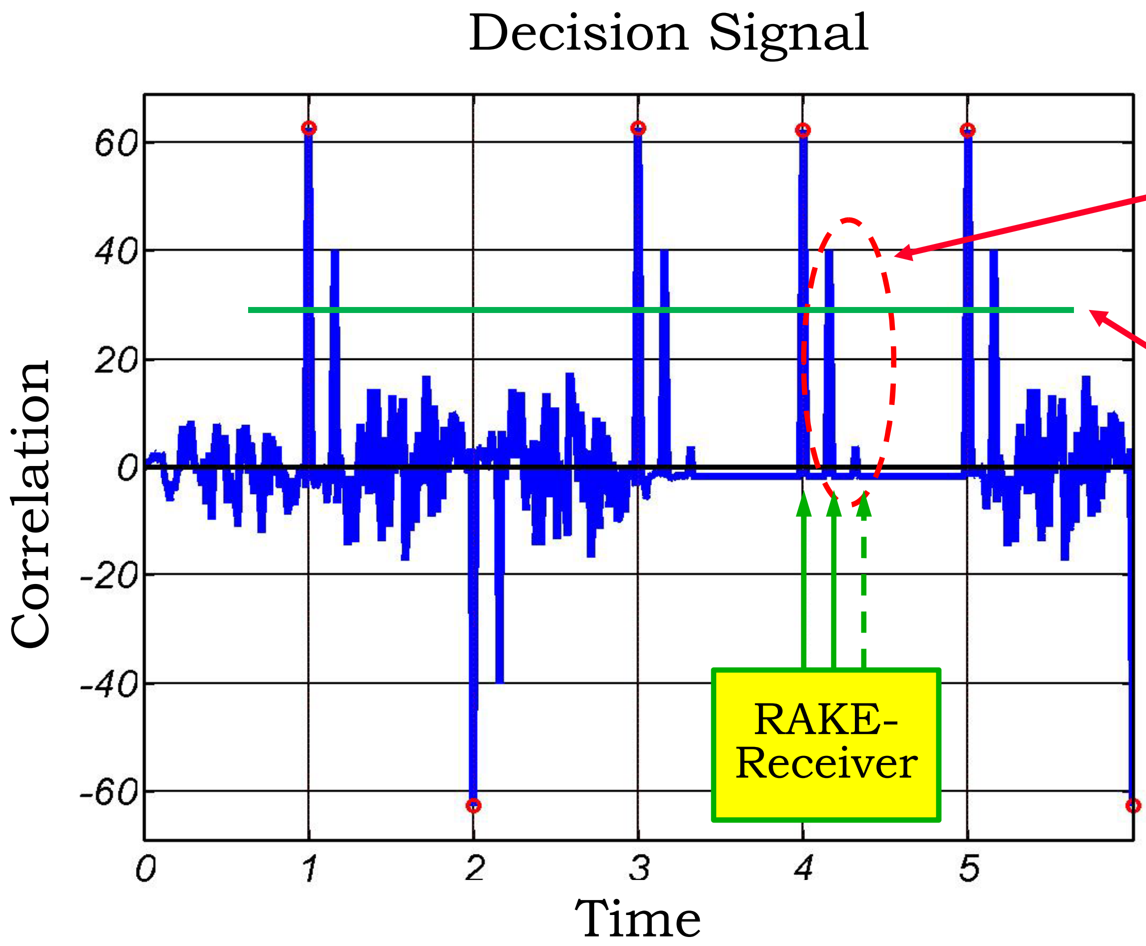


Mutipath - MRR

Multipath Rejection Receiver [active MF]



Spread-Spectrum: RAKE-Receiver

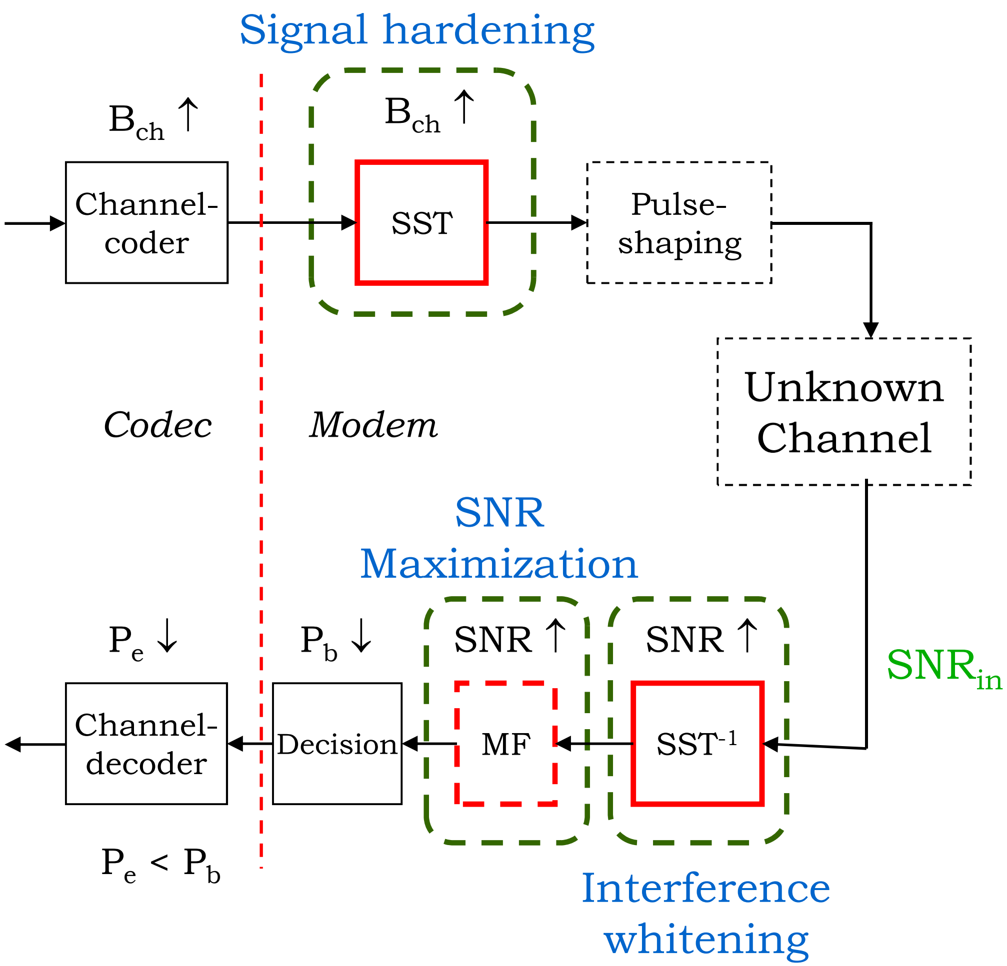


Constructively included in the decision variable

(Radio-)Resouce-Management: Threshold decides if MP-component is included in the decision variable.

Exploiting the pseudo-random property of the spread-spectrum signal.

Structure of a Spread-Spectrum System (SST)



Higher Layer: Operations on symbols.

Physical Layer: Operations on waveforms.

Remark-Coding:
The „coder“ processes bits to form symbols and prepare the information with parity bits (redundancy = bandwith expansion) to reduce the SEP.

Remark-SST:
The SST processes waveforms and protect the information from unknown channel attacks (interference whitening = bandwidth expansion) to improve the SNR.

Spread-Spectrum: (R)evolution

Single Code Transmission: ➡ Combat unpredictable kinds of interference including multipath interference rejection.

RAKE-Receiver: ➡ Resolve multipath components.

CDMA: ➡ Multi exploitation of the channel.

Multi Code Transmission: ➡ Enhance efficiency.

Spread-Spectrum: (R)evolution con‘t

Multi-User Detection: ➡ Combat the multi-user interference.

Multi Carrier Code Transmission (MC-CDMA):

➡ Combat the multi-user interference using the collision avoidance principle.

Radio Resource Mangement:

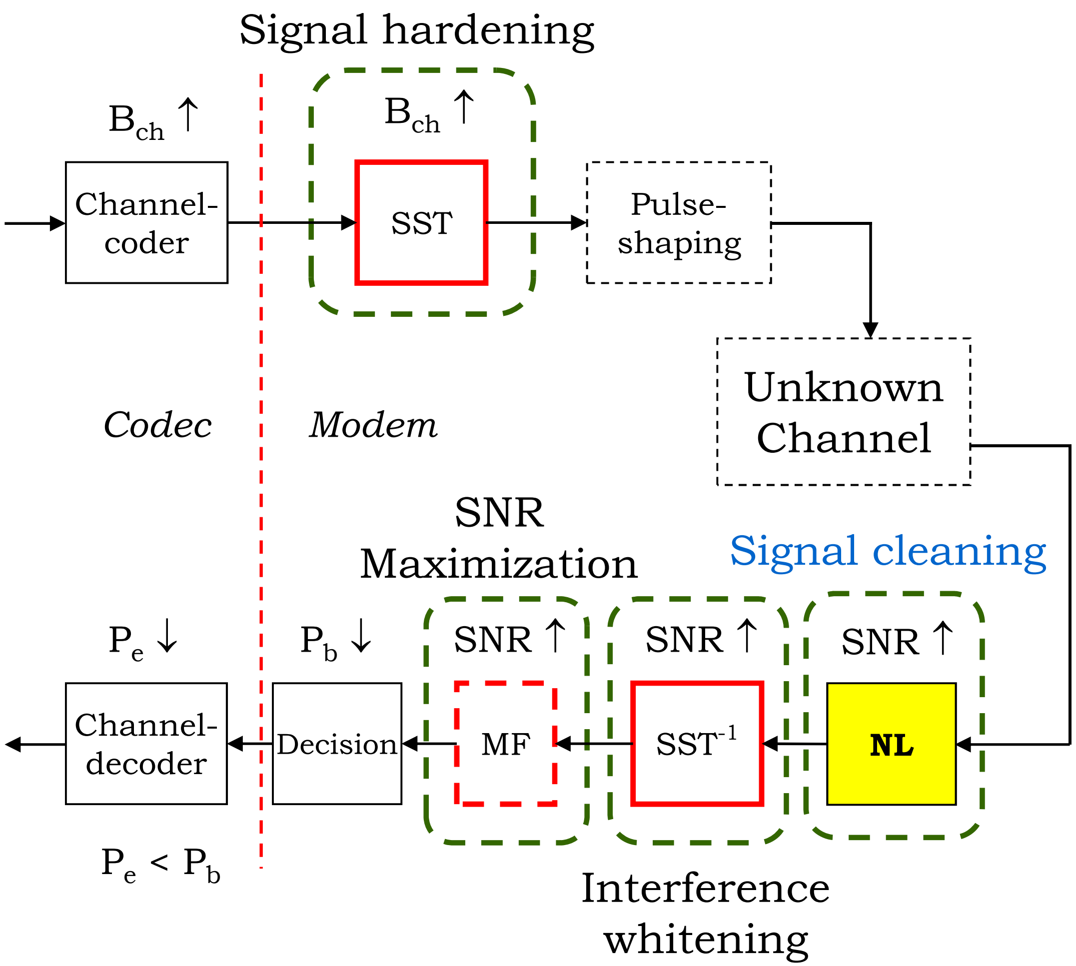
➡ Exploites the flexibility of the spread-spectrum philosophy.

The next step beyond spread-spectrum

Robust & Reliable Systems:

Spread-Spectrum Technolgy
+
Nonlinearity

Overall Structure of an Efficient Robust System



Higher Layer: Operations on symbols.

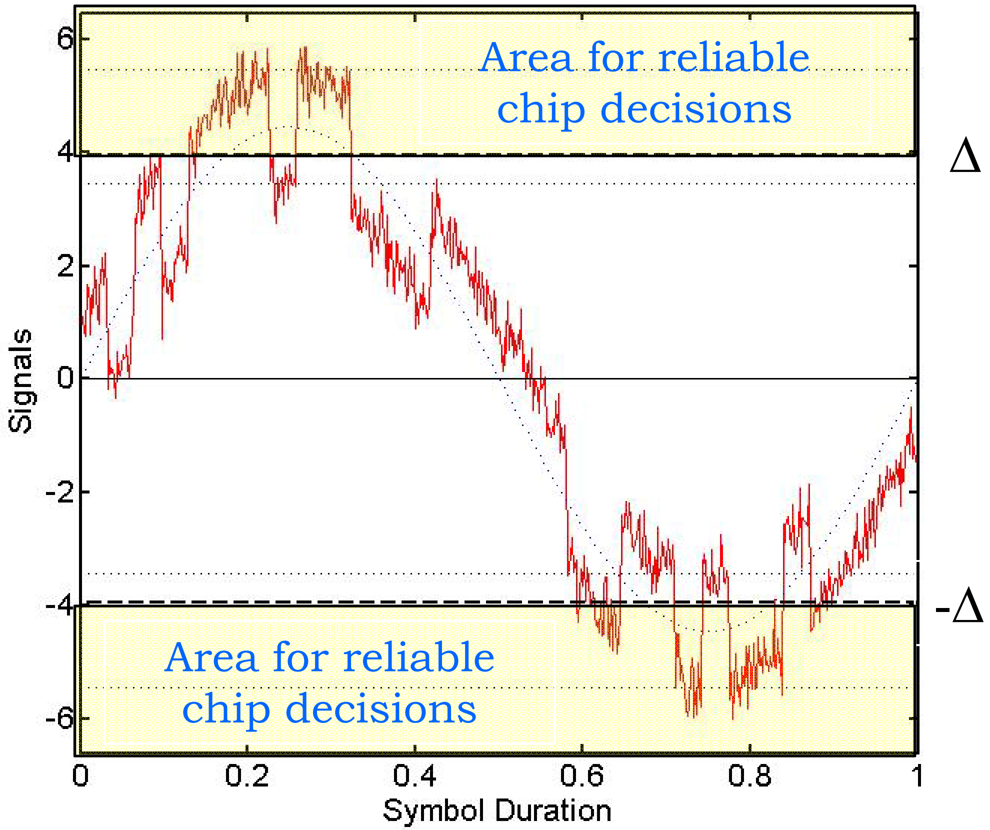
Physical Layer: IR-Operations on waveforms.

Remark-Coding: The „coder“ processes bits to form symbols and prepare the information with parity bits (redundancy = bandwith expansion) to reduce the SEP (P_e).

Remark-SST: The SST processes waveforms and protect the information from unknown channel attacks (interference whitening = bandwidth expansion) to improve the SNR.

Remark-NL: The NL processes waveforms to reduce the interference magnitude.

Example: Broadband and narrowband interference present at the same time.



.... Adjustable Threshold

Input Signal Sample:

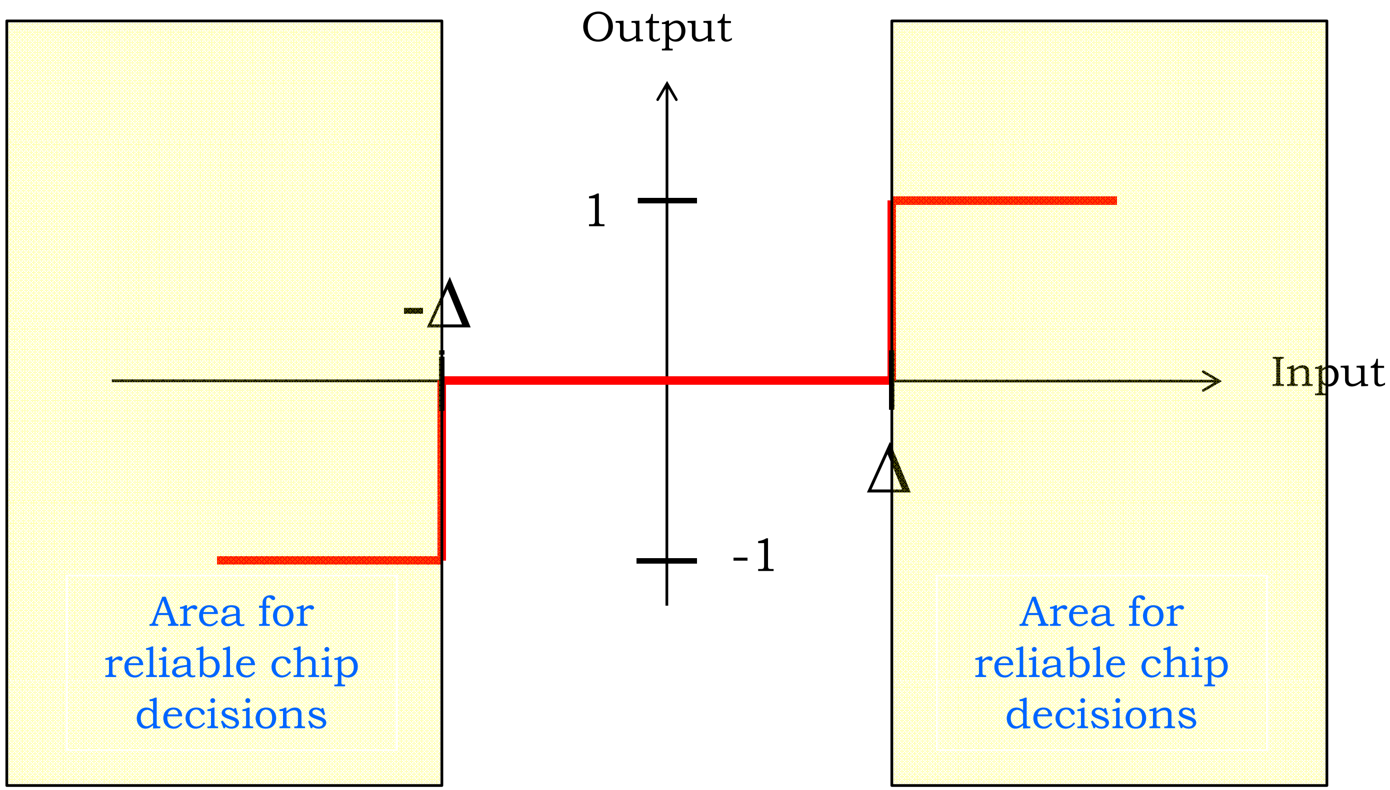
AWGN: Represents broadband interference.

Continuouse Wave: Represents narrowband interference.

An Efficient Robust & Reliable Communication System

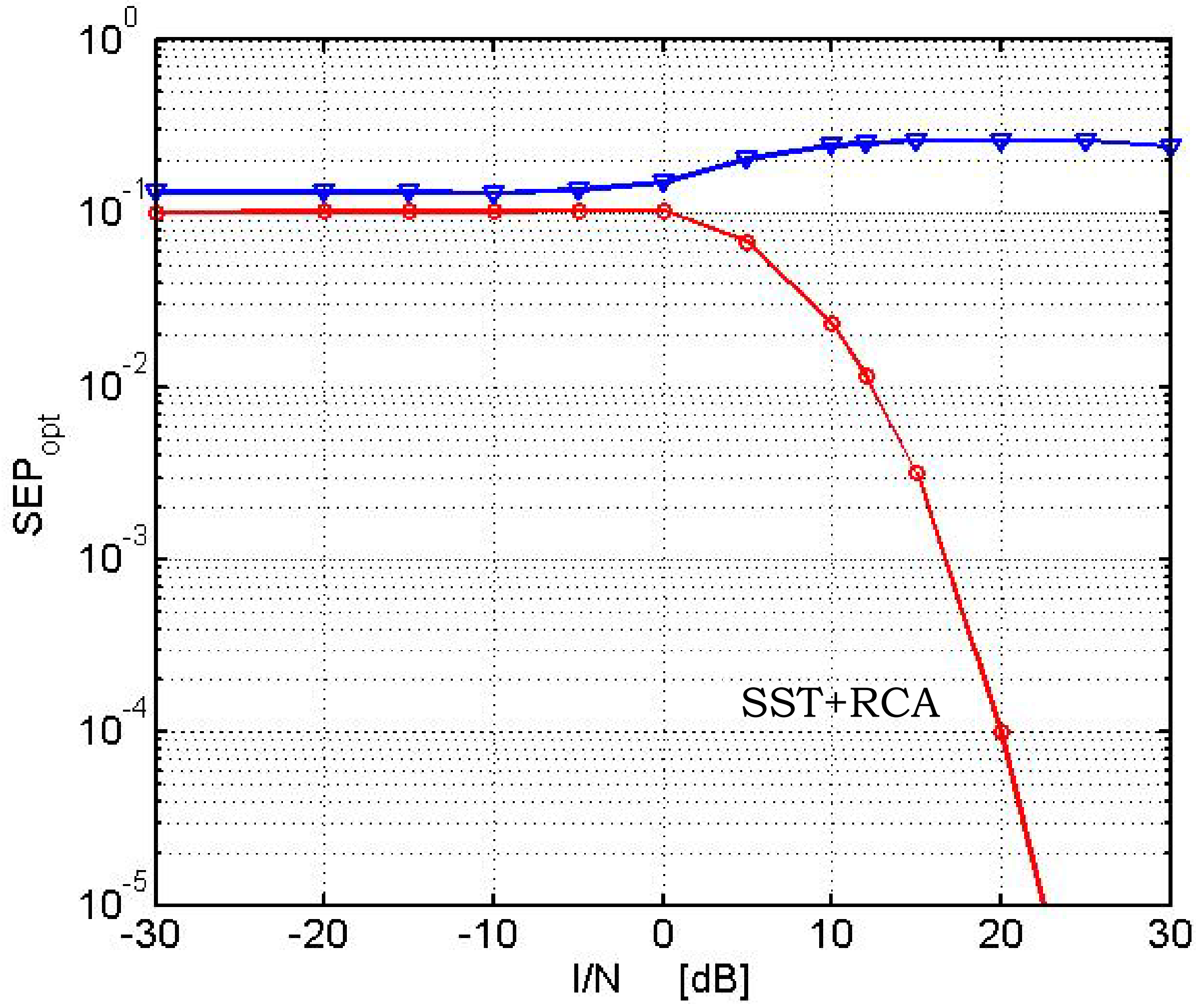
Nonlinearity ➡ **RCA-Nonlinearity**

RCA … Reliable
Chip Accumulator



An Efficient Robust & Reliable Communication System

Performance



SST+Hard-Limiter

Remarks:
The new robust and reliable system outperforms it‘s counterpart (compareable complexity).

Conclusion

From Robustness follows Reliability.

Robustness ⇨ **Reliability**

[1] Low complexity (simple)
[2] Small size
[3] Light weight
[4] Simple algorithms
[5] Flexible services
[6] Scalable performance
[7] Adaptive interference reduction
[8] Easy resource management

[1] Less power consuming
[2] Low error-probability
[3] Long lifecycle
[4] High availability
[5] Independent of environment
[6] Stabel algorithms

Thank you for your attention.

Alois Goiser: Biography

Alois M.J. Goiser is a member of the Faculty of Electrical Engineering and Information Technology at the University of Technology Vienna, Austria. Currently he holds the position of an associate professor. He is the head of the "Robust and Reliable Communications"-group at the Institute of Communications and Radio Frequency Engineering.

He is involved in spread-spectrum applications since 1988. His research interests are interference reduction schemes in general, CDMA-networks, multi-user detection, synchronization of RAKE-receivers. His focus is on low-complexity digital transceivers for robust and reliable communications.

He was the technical program chair of Eurocomm2000 and has published more than 80 technical papers, one book and contributions to books. He headed many projects with industry and the European Community.