SDR – Software Defined Radio

Modern Concepts for Receivers and some Facts behind their Designs

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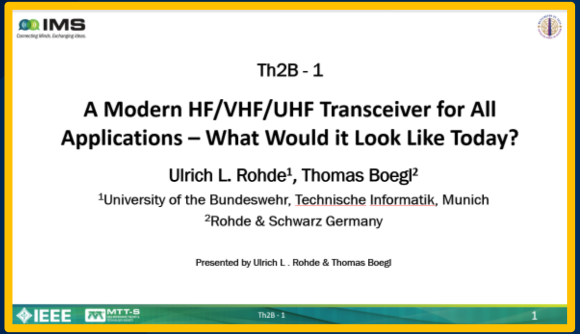
IMS Washington on June 20th 2024



MIT, Boston Massachusetts on May 6th 2024

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CONTENT

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  - We start with 3 slides of SDR history just to warm up
- Part 1:
  - Use Cases and beyond
  - Main Reqirements and their Influence to an SDR Architecture
- Part 2:
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  - Placing an ADC into a receivers block diagram
- Part 3:
  - Setting up an SDR Receiver Architecture
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- Part 4:
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SOME HISTORY ABOUT SDR FIRST – JUST RELAX

1.1 Wireless Communication enabled by electromagnetic Waves.

It all started with James Clark Maxwell´s prediction that electromagnetic wave should exist. This statement sparked the curiosity of many researchers who either wanted to refute or confirm his remarkable thesis.

Fig 1: James Clark Maxwell predicted electromagnetic waves

One of the first to prove the existence of electromagnetic waves was Heinrich Hertz. In the year 1886 he successfully showed the transmission of electromagnetic waves from a transmit antenna to a receive antenna. Within his first test setup he already used elements which became standard in radio communication systems like dipole antennas, and also a metallic parabolic reflector was used to improve the gain of his transmit antenna.

Fig 2: Heinrich Hertz proved the existence of electromagnetic waves

The unit "Hertz" for the frequency of electromagnetic signals and the "Hertzian Dipole" remind us of the great influence of Heinrich Hertz to wireless communication technology.

SOME HISTORY ABOUT SDR FIRST – JUST RELAX

1.2 Form Theory to Experiments and finally to practical Use

Photo: Rotary Photo, London. Nobel Foundation archive
Guglielmo Marconi
Prize share: 1/2

Photo from the Nobel Foundation archive.
Karl Ferdinand Braun
Prize share: 1/2

Fig 3: Marconi and Braun share the Nobel Prize for Physics

During the presentation speech at the Nobel Prize ceremony given by the former Rector General of National Antiquities H. Hildebrand, President of the Royal Swedish Academy of Sciences, on December 10, 1909 he points to these facts:

We cite (from https://www.nobelprize.org/prizes/physics/1909/ceremony-speech):

The discoveries and inventions for which the Royal Academy of Sciences has decided to award this year's Nobel Prize for Physics, also have their origin in purely theoretical work and study. Important and epoch-making, however, as these were in their particular fields, no one could have guessed at the start that they would lead to the practical applications witnessed later.

He further tried to give an outlook:

Where this development can lead, we know not. However, with the results already achieved, telegraphy over wires has been extended by this invention in the most fortunate way. Independent of fixed conductor routes and independent of space, we can produce connections between far-distant places, over far-reaching waters and deserts. This is the magnificent practical invention which has flowered upon one of the most brilliant scientific discovery of our time!

SOME HISTORY ABOUT SDR FIRST – JUST RELAX

1.5 From the SDR Idea to practical Use

First SDR implementations appeared in the 1980s. In 1982, while working under a US Department of Defense contract at RCA, Ulrich L. Rohde's department developed the first SDR. Ulrich L. Rohde was the first to present on this topic with his February 1984 talk, "Digital HF Radio: A Sampling of Techniques" at the Third International Conference on HF Communication Systems and Techniques in London

Fig 7: Ulrich L. Rohde – the father of practical SDRs

The SDR technology was now recognized as an enabler for an extremely wide field of applications. Within the following years a huge number of SDR realizations were introduced to the market. SDRs can be found in all applications where radios are operated. SDRs can be found in space, in the air, on board of ships and many other platforms. Military users rely on the flexibility of SDRs as the basis for a long period of use without the need to change the complete radios when new waveforms are required. Radio amateurs show an incredible creativity inventing new applications and waveforms which are quite often available as download free of charge from the internet.

PART 1

1. Use Cases and beyond
2. Main Reqirements and their Influence to an SDR Architecture

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WHAT IS THE BEST POSSIBLE SDR DESIGN?

Let´s assume that somebody asked you this question, what would you answer?

We recommend to ask first the following two questions (at least these two):

- What is the Use Case ?
- Where shall the equipment be installed or used ?

} This is the most important stage within a development project when it has not yet started and is e.g. in a phase of planning and calculation. Therefore we will ask even more questions later.

Why?

A concept which is **perfect for** Use Case **Scenario** A **can be useless for** another Use Case **Scenario B**.

If the right questions are not answered at the beginning some severe things may happen → Do you know the ESA „Cassini - Huygens Mission“ which almost failed ? Because some questions about the use case haven´t been asked before the rocket was launched !

With this starting point we will compare different products and will have a detailled look into their RF concepts

DIFFERENT USE CASES LEAD TO DIFFERENT RF CONCEPTS

Ultra - Broadband Monitoring Receiver

WPU2000

Spectrum Analyzer / EMI Test Receiver

FSW / ESW

Handheld Receiver

PR200

Communication Receiver

SDHR

M3SR

M3AR

SDTR

DIFFERENT USE CASES LEAD TO DIFFERENT CONCEPTS

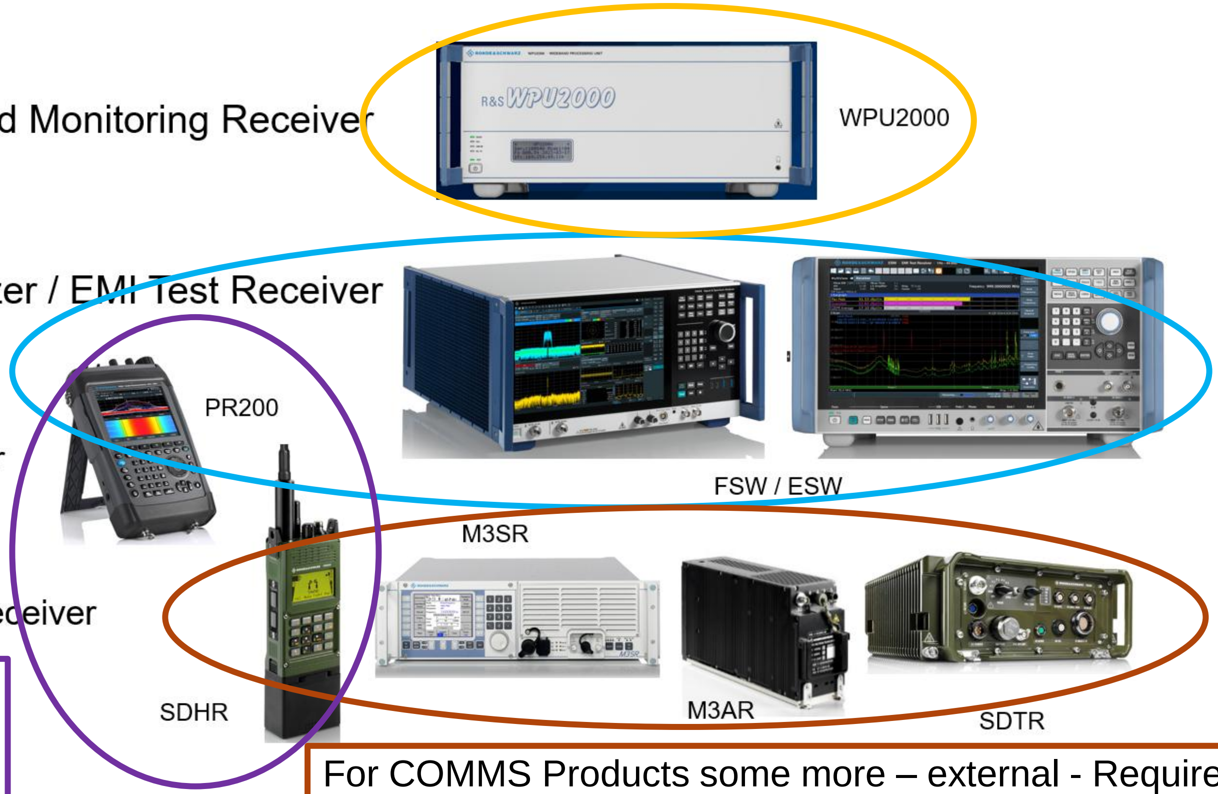
FINDING THE RIGHT CONCEPT IS TRICKY AND DOES NOT ONLY CONTAIN EASY TECHNICAL ASPECTS

Ultra - Broadband Monitoring Receiver

Spectrum Analyzer / EMI Test Receiver

Handheld Receiver

Communication Receiver



Wide Frequency Range
High Dynamic Range
Ultra high Detection Speed to find short Events

Ultra wide Frequency Range
High Dynamic Range, High Resolution (ΔF)
High Measurement Speed → time is money

Moderate Frequency Range
Dynamic Range from Ultra high (Vehicular) to moderate (Handheld)
Highly robust (operational Environment)

Small SWaP-C

- Low Size
- Low Weight
- Low Power
- Low Cost

For COMMS Products some more – external - Requirements apply:
Interoperability to „NON - R&S“ Waveforms and Crypto e.g. for NATO
Seemless Integration in already existing military Systems and Procedures
Flexibility for fast Adaptation to new Waveforms (the SDR Idea as such)

Plus in general:

- what the customer wants
- what the customer needs
  - what he must do to fulfill his obligations e.g. within a Defence Union like NATO

We continue now with the RF Aspects only
At the end we will come back to some of the other topics e.g. Implementation Aspects

LET´SLOOK A BIT CLOSER TO THE INSTALLATIONS

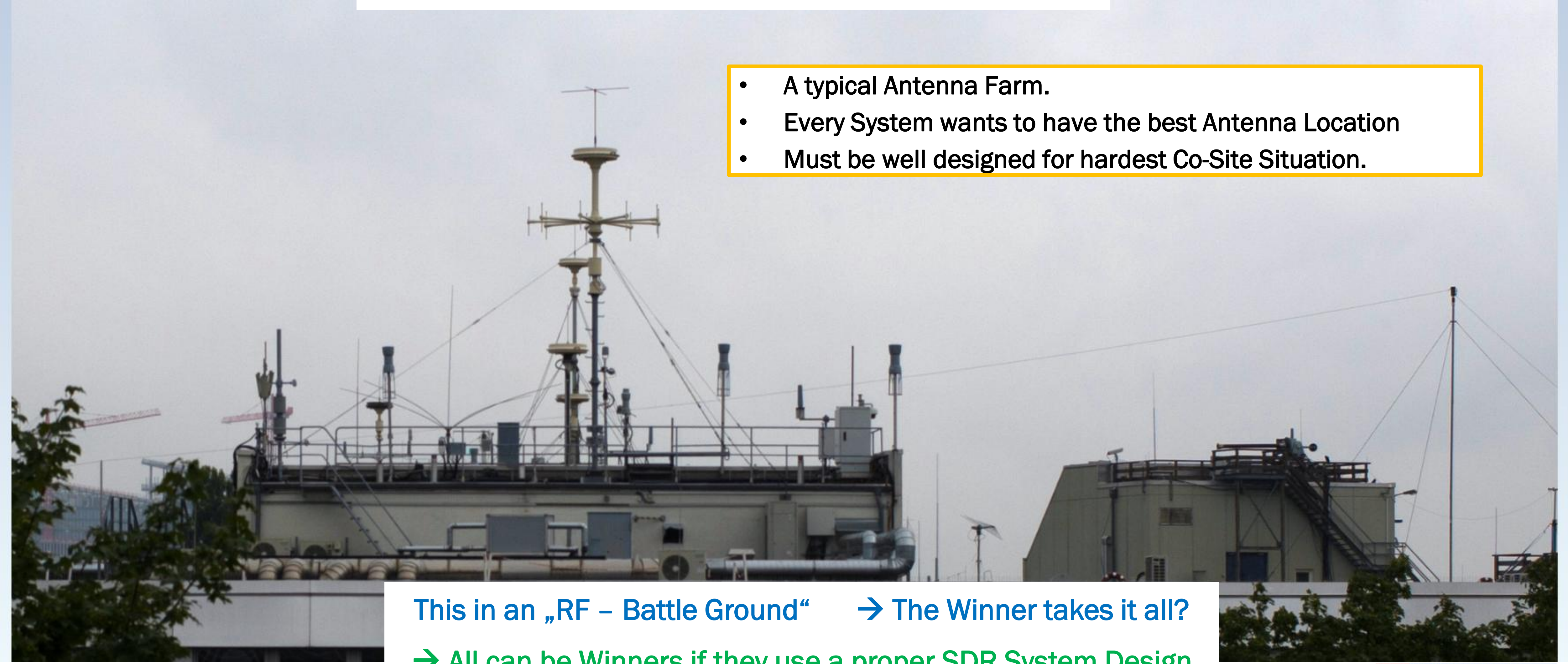
- We look now to System Installations for SDRs and derive the consequences for SDR designs

- And again more questions:
  - Are there strong interferers close by? (with respect to decoupling in dB and frequency separation)
  - If we intend to transmit: Are there any systems close by which could be negatively influenced?
  - What communication modes/waveforms shall be used?
    - A comment: Systems using analog modes e.g. AM DSB for ATC use can mean real challenges for the receiver architecture

- Whe must know where the limits for a particuar technical approach will be.
- This is important to allow an optimization (business case!)

LET´S LOOK INTO THE PRACTICAL USE

- SIMOP → simultaneous Operation - Collocation



- A typical Antenna Farm.
- Every System wants to have the best Antenna Location
- Must be well designed for hardest Co-Site Situation.

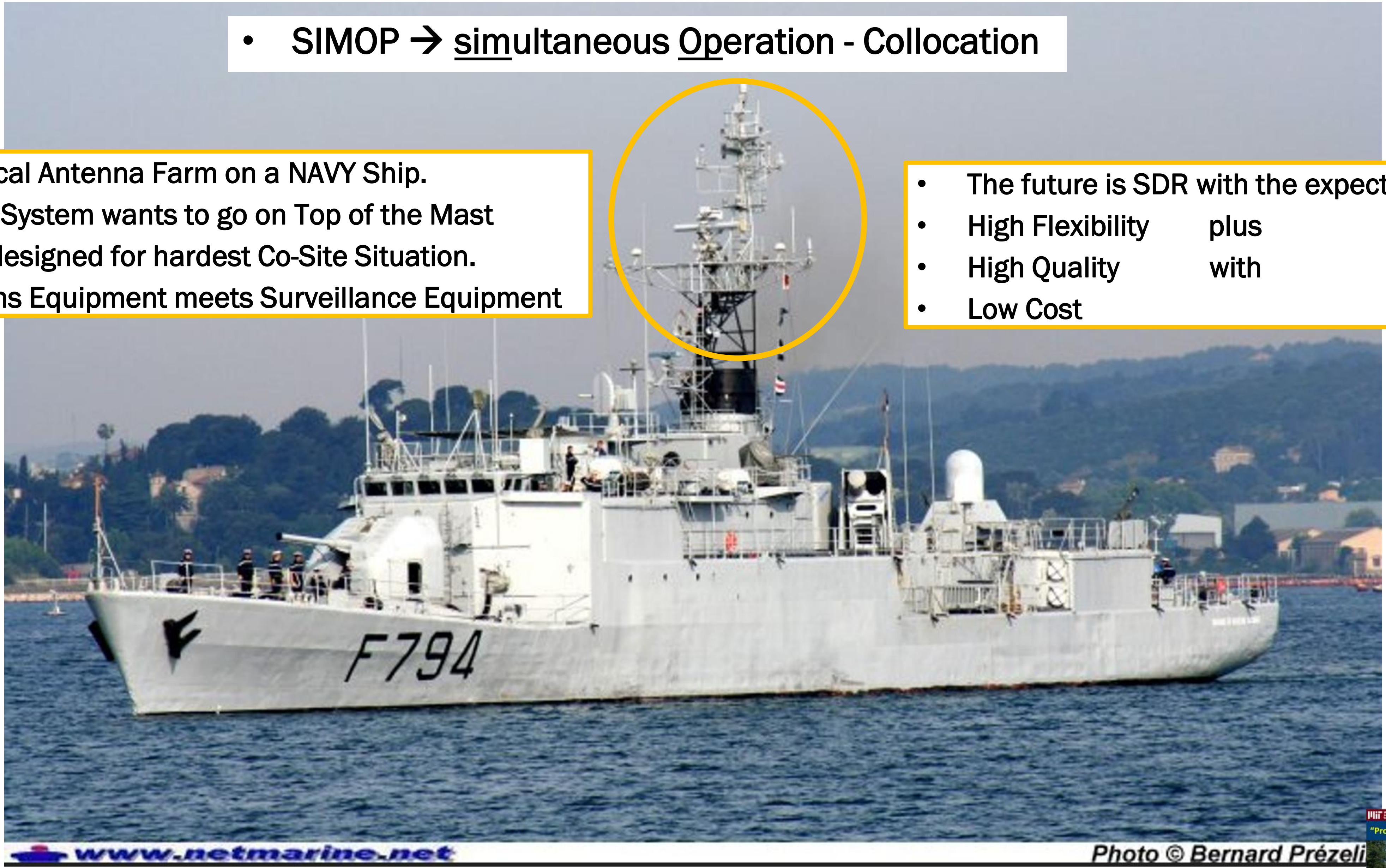
This in an „RF – Battle Ground“ → The Winner takes it all?

→ All can be Winners if they use a proper SDR System Design

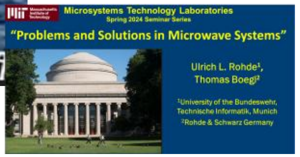
LET´S LOOK INTO THE PRACTICAL USE

- SIMOP → simultaneous Operation - Collocation

- A typical Antenna Farm on a NAVY Ship.
- Every System wants to go on Top of the Mast
- Well designed for hardest Co-Site Situation.
- Comms Equipment meets Surveillance Equipment



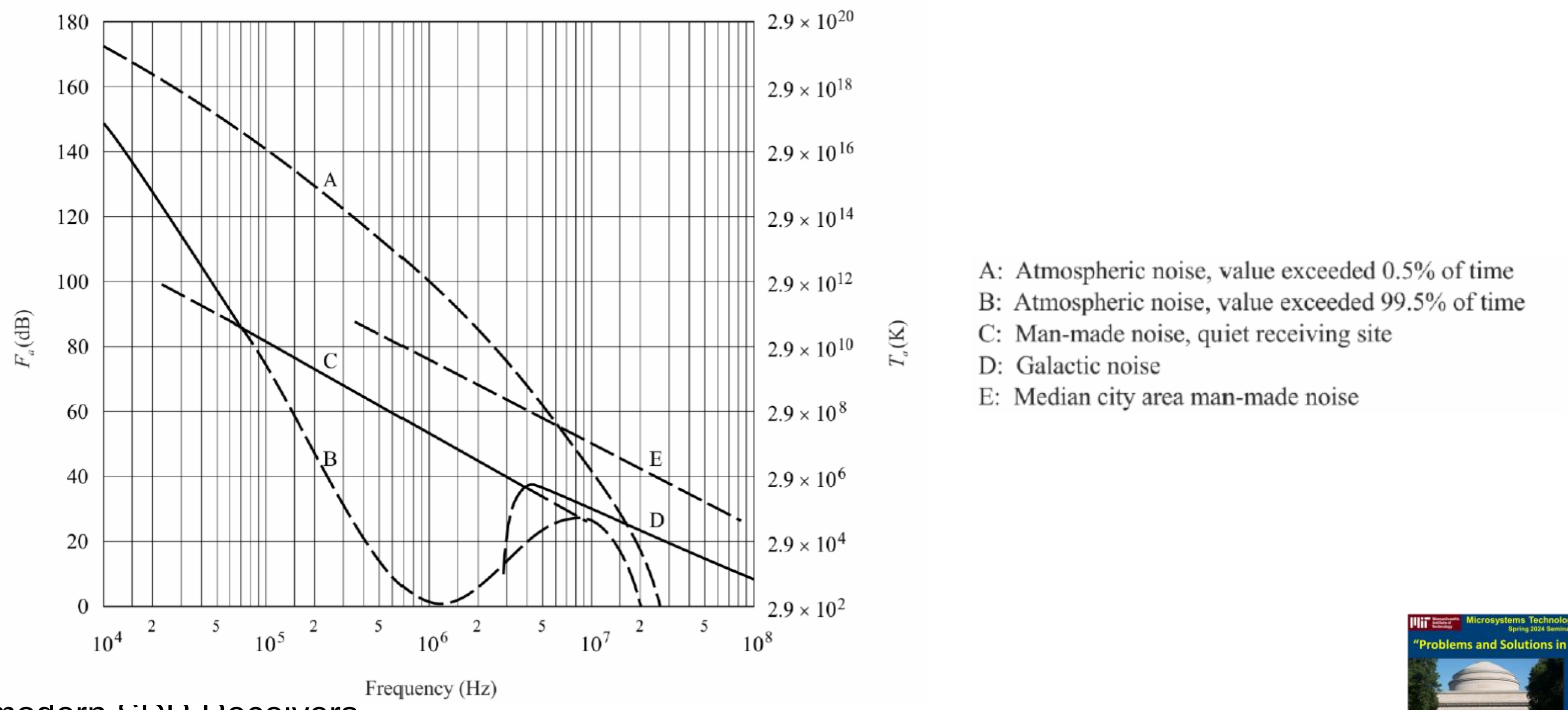
- The future is SDR with the expectation of
- High Flexibility plus
- High Quality with
- Low Cost



STARTING POINT - 1

- Modern Receivers / Transmitters / Transceivers are all Software Defined Radios → SDR
  - We are partly taking into account also transmiters today, even when we focus only on designs for receivers
  - Why:
    - If we understand the design behind interfering transmitters we can probably simplify our RX design
    - If we understand external influences into a receiver as such we can “hide” some parameters and use this as a potential for improvements

Rec. ITU-R P.372-15



STARTING POINT - 2

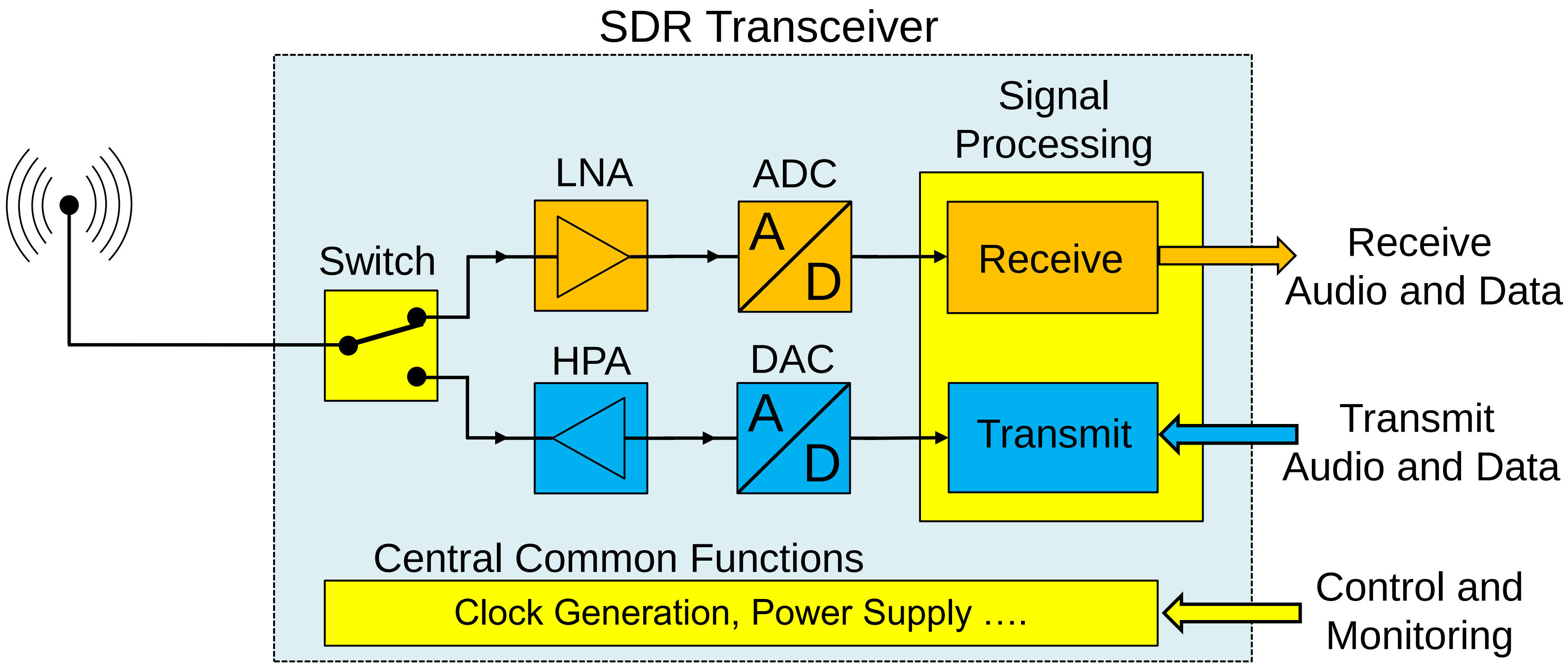
- ► Is it all about Software (only) in future SDR Technology?
  - – What about the SDR Hardware? → This is an essential part!
  - – Which SDR Hardware is the best? → it depends!
    - – On What? → on the planned Application and the Use Case for the SDR
  - – And the way "how to implement SDR SW" is essential for the usability, flexibility and development cost. This is one major influence to achieve e.g. "Truppentauglichkeit" (usability for the operators)

  → we will look to that at the end of this presentation → Implementation Aspects !

- ► Let´s start now and derive together:
  - – A modern – SDR based – HF/VHF/UHF Transceiver for All Applications

Ideal SDR

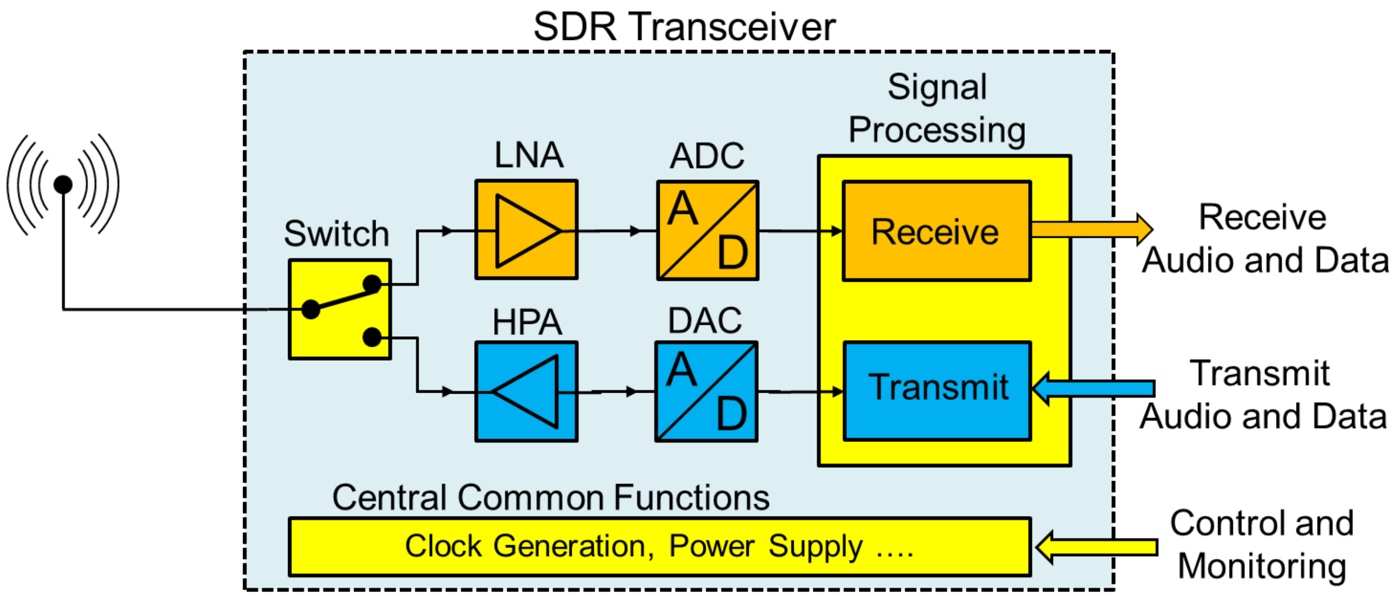
- ADC and DAC are operated directly at the Antenna

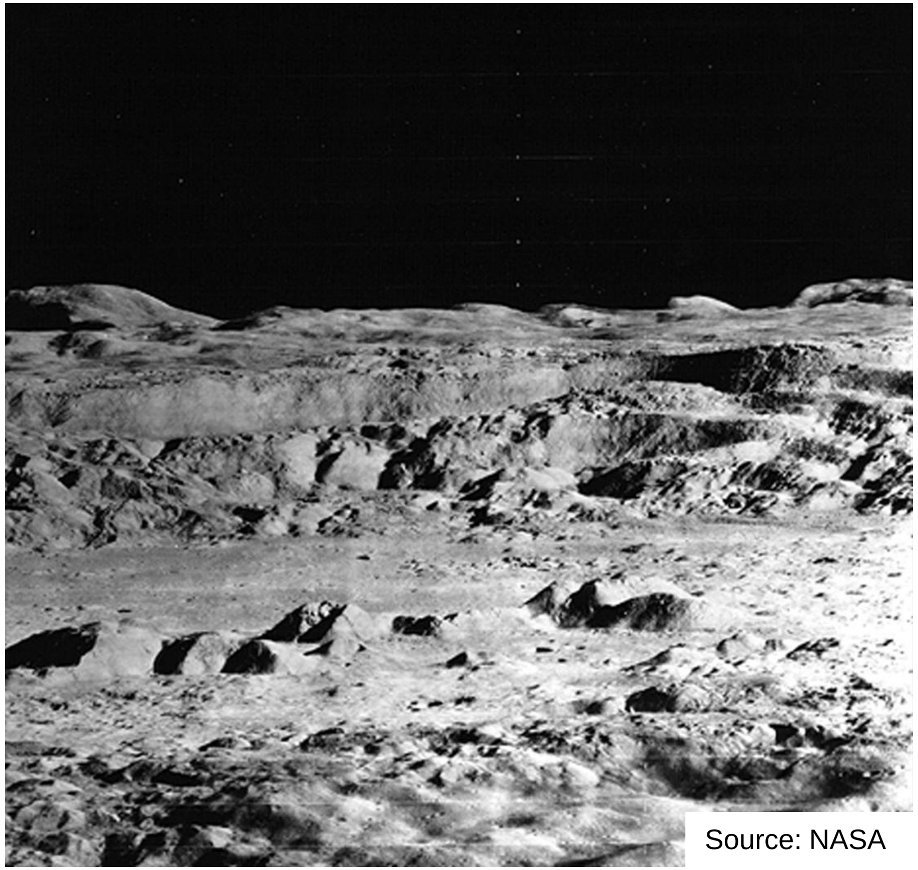


- Where can we operate this ideal SDR?

Ideal SDR

- Where can we operate an ideal SDR?





Source: NASA

- Only in “quiet” zones without any other Transmitters <u>and</u> Receivers nearby.

Our ideal SDR within a Cosite Situation

- The most critical RF Parameters are the following:
  - In RX Mode:
    1. Crossmodulation
    2. Desensitization
    3. Intermodulation
    4. Spurious Reception

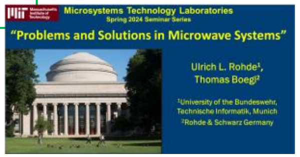
    Protection against strong Interferers outside our own Receive Channel

    → Setting our own Receive Performance

  - In TX Mode:
    1. Noise
    2. Discrete Spurs

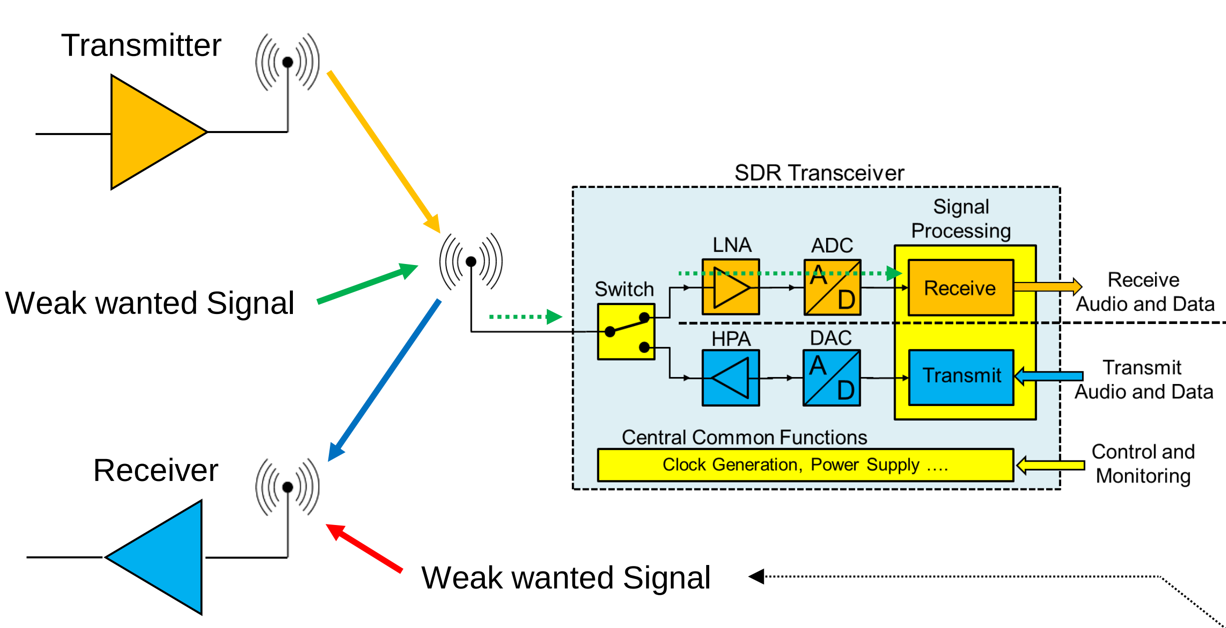
    Protection of other Receiver Systems outside of our own Channel

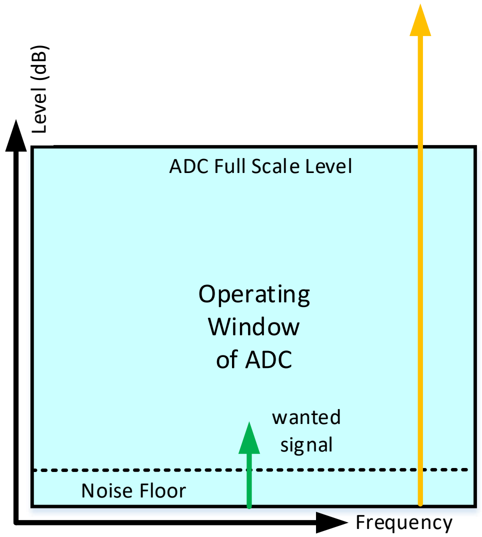
    → Our Responsibility to protect other Systems if we intend to Transmit



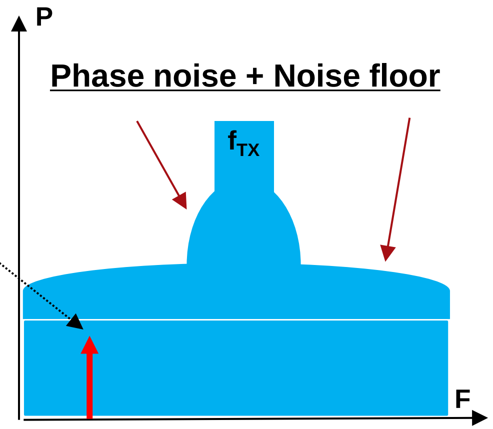
Our ideal SDR within a Cosite Situation

- A nearby Transmitter may saturate our ADC





- We have to ensure that all Receive Signals are within the Operating Window of our ADC



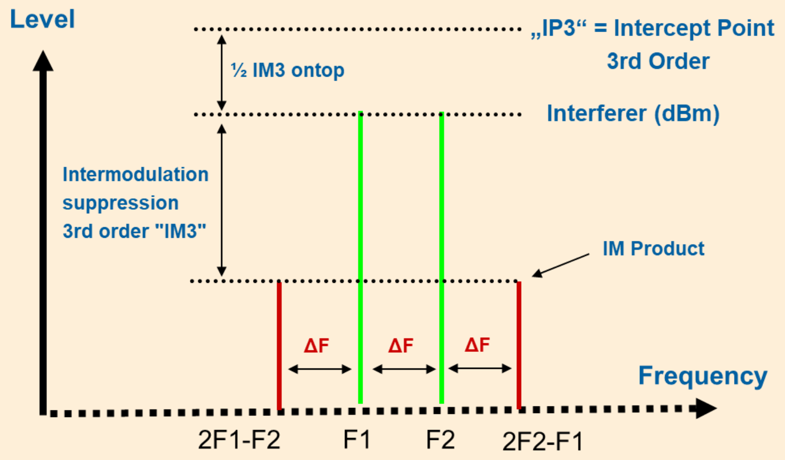
- We have to ensure that our Transmit Signals are not masking another Receive Channel

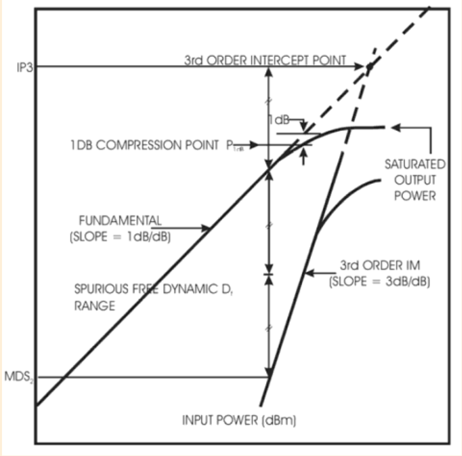
- A nearby Receiver may be desensitized by our SDR´s Transmitter noise

Full analog versus full digital

- Nonlinear Effects within the Receiver Architecture may create unwanted Signals

- Conventional Receiver Architecture

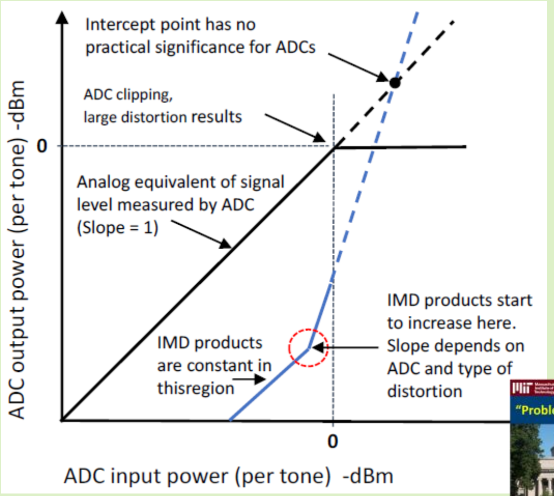




  - How it works:
    - A 1 dB increase in the level of the interferers results in a 3 dB increase for the IM products, IM3 is reduced by 2 dB.
    - If one interferer increases by 1 dB, the intermodulation products also rise by approx. 1 dB → IM3 unchanged.

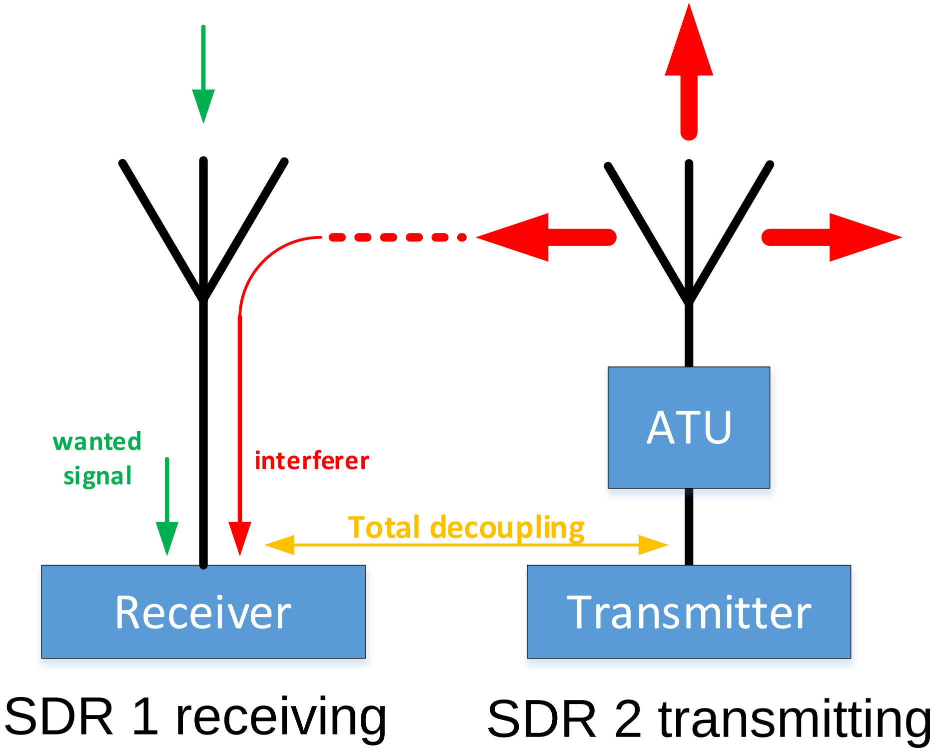
- Ideal SDR Receiver Architecture = ADC at Antenna

- How it works:
  - ADCs do not have an 1 dB Compression point.
  - IP2, IP3 characterizations do not apply here.
  - Intermodulation Products may appear through all levels



Our ideal SDR within a real Cosite Situation

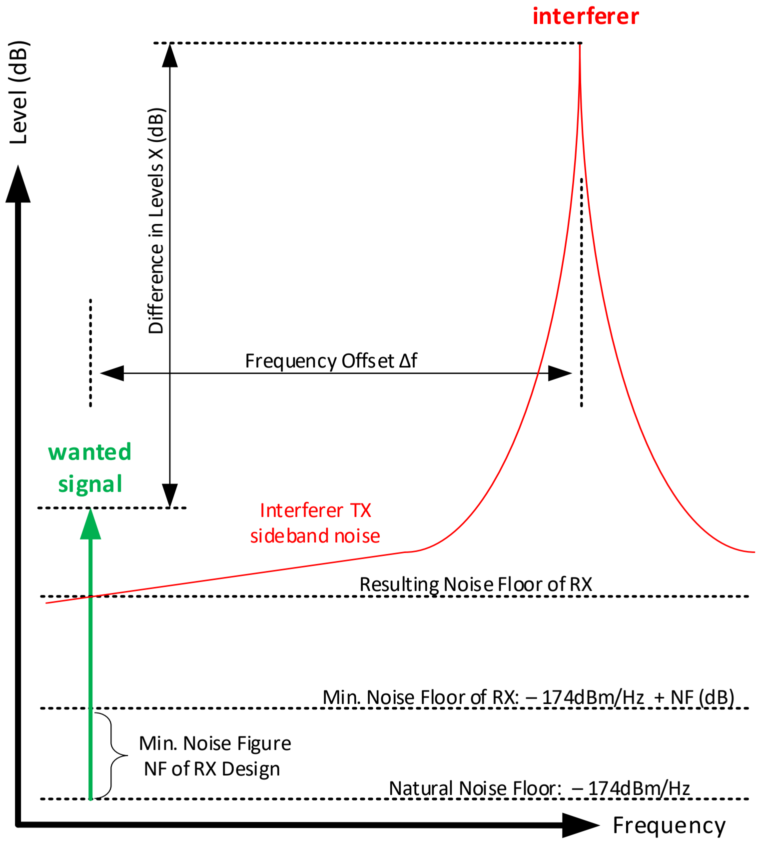
- The most critical RF Parameters are derived from here:
  - Two of our SDR Transceivers are operated side by side
  - The Transmitter of one SDR is probably saturating the receiving SDR



- Based on this configuration all relevant Transmitter Parameters can be calculated:
  - Total decoupling (= antenna coupling including all losses e.g. cables etc.)
  - Interfering Transmitter Power at Receiver Input
  - Frequency Offset between the Receive Channel and the Transmitters Channel

Our ideal SDR within a real Cosite Situation

- The Quality of the Transmitter Signal can be derived from here:
  - The noise of the nearby Transmitter may mask our Receive Channel



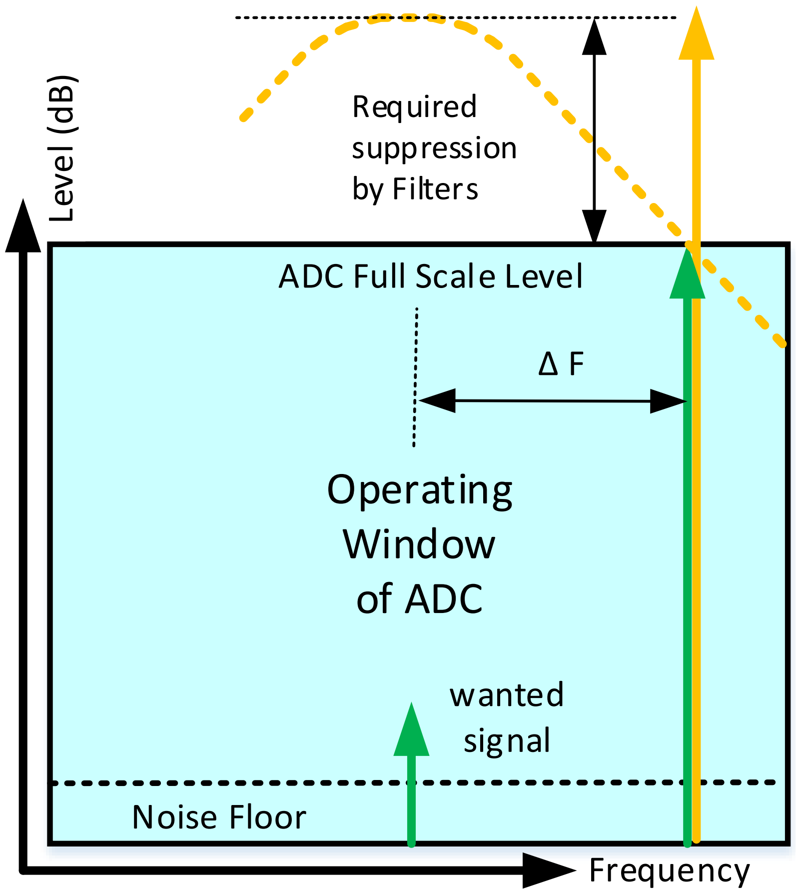
- Based on this configuration the max. allowed Transmitter Noise can be calculated:
  - The reference is the Receivers equivalent Input Noise Floor.
  - In combination with the total decoupling between the Receiver and the nearby Transmitter the max. allowed Transmitter Noise Floor can be calculated for a wanted acceptable Desensitization.

Our ideal SDR within a real Cosite Situation

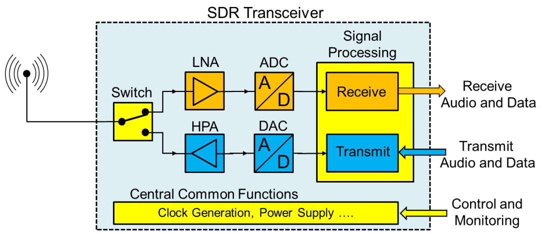
- Which Values do we need for a good Cosite Performance?
  - In RX Mode:
    - Noise Figure: 4 dB (with LNA within quite Zones)
    - Noise Figure: 10 dB (without LNA within congested Environments)
    - Max. Interferer level at RX below 30 MHz: + 27 dBm @ ≥ 100 kHz
    - Max. Interferer level at RX above 100 MHz: + 17 dBm @ ≥ 10 %
    - Intermodulation Performance IP3: > + 40 dBm
  - In TX Mode:
    - Transmitter Noise: - 180 dBc/Hz or even better for vehicular Comms
    - Discrete Spurs: less than -100 dBc

Enhancing our ideal SDR → "real" Receiver

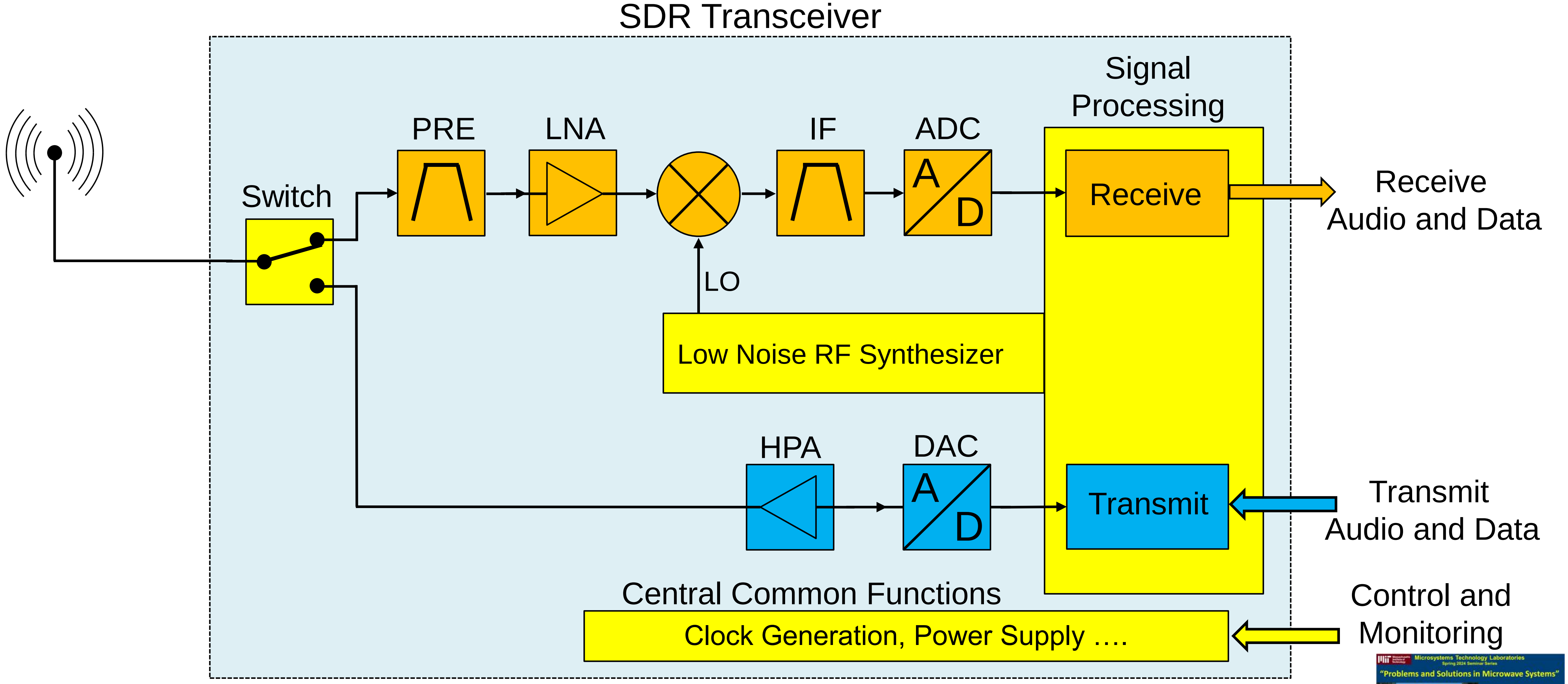
- We have to suppress all strong unwanted signals and "squeeze" them into the operating window of our ADC
  - This can be done e.g. by pre – selector filters (tunable)
  - Or it can be done by filters at an IF frequency within a superhet concept
  - Or with both
- Comment:
  - It is easier to built a superhet concept than an ultra wide tunable highly selective pre – selector filter



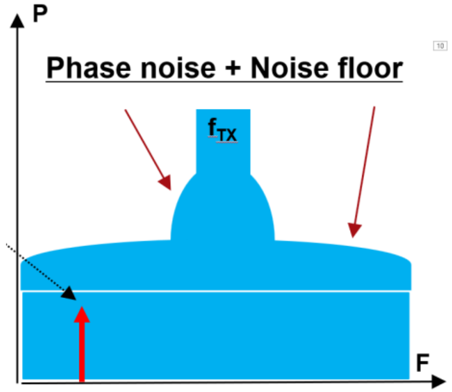
Enhancing our ideal SDR → Receiver



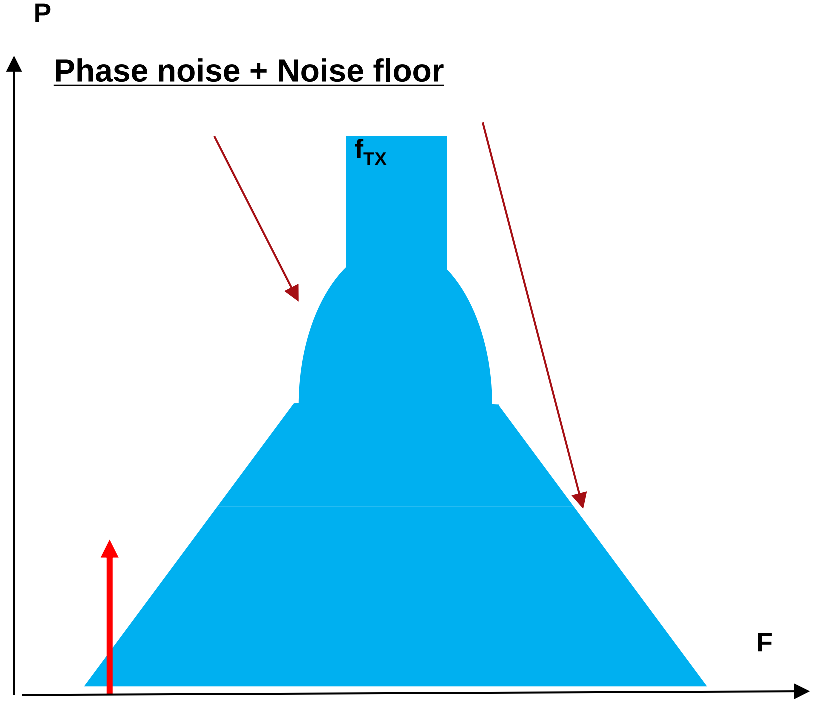
- Introducing a Pre – Selector Filter <u>AND</u> an IF Filter



Enhancing our ideal SDR → Transmitter

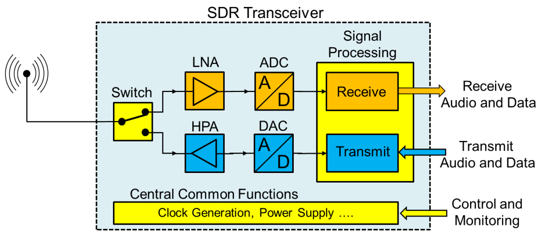


- We have to improve our Transmitter Noise Floor to ensure that no other Receive Channel is filled with our Noise
  - This can be done e.g. by using RF Filters within the Transmitter Path
  - This Filter will be carefully designed into the Transmitter Path.

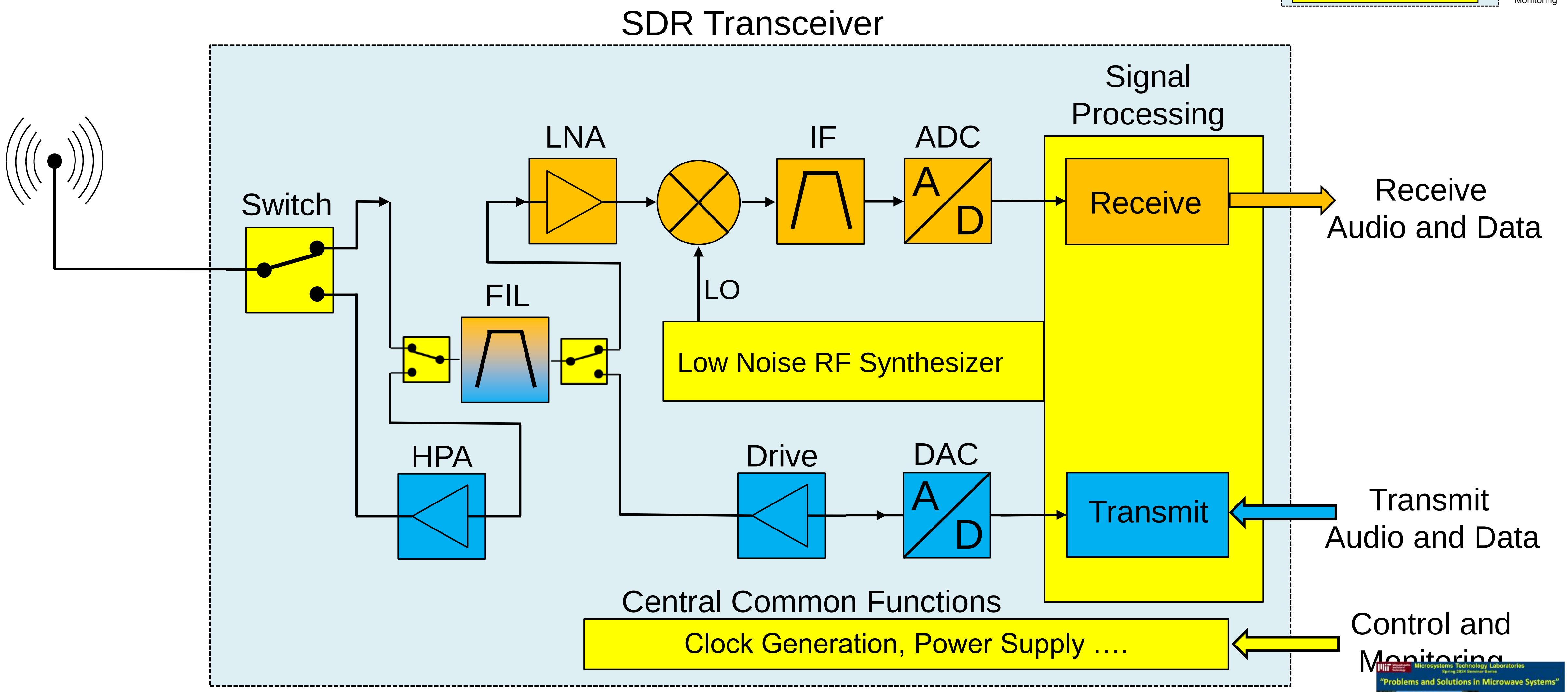


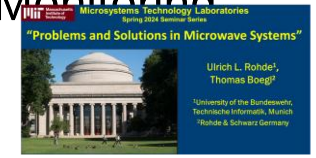
- Comment:
  - A high quality Transmit Filter can be reused as Pre – Selector Filter for the Receiver Path

Enhancing our ideal SDR → Transceiver



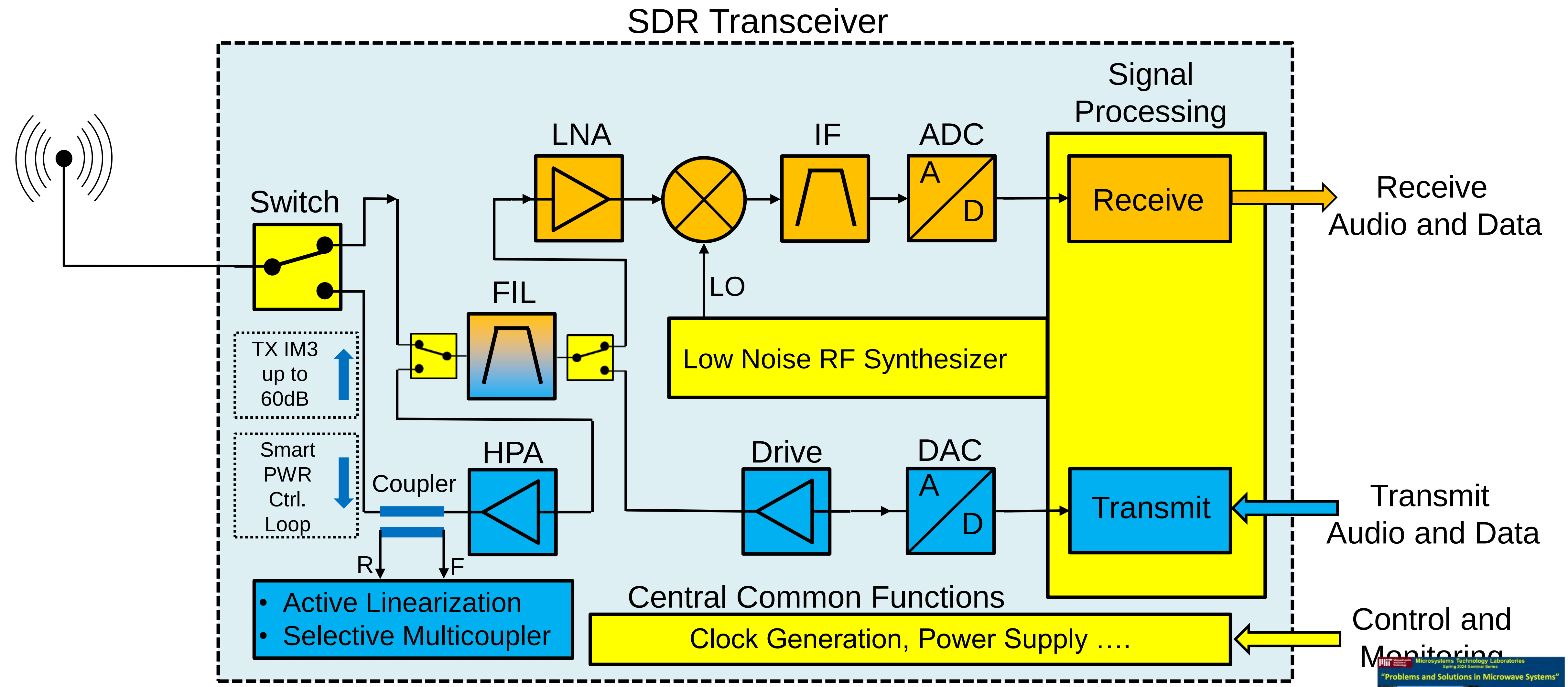
- Introducing a Pre – Selector Filter AND an IF Filter

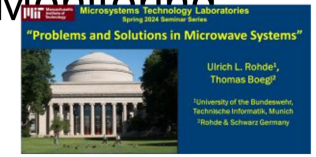




Enhancing our ideal SDR → Transceiver

- Introducing a Pre – Selector Filter AND an IF Filter AND active Linearization





Conclusion for Part 1

- A High End Software Defined Radio requires a High End Hardware Block Diagram to enable an High End RF Performance.
- The planned Applications and Use Cases define the required RF Data Sheet.
  - SDRs for HF, VHF, and UHF may require significant different Block Diagrams compared to SDRs in the GHz Ranges.
  - At lower RF Frequencies with low Antenna Decoupling Values within Installations IF Sampling wins.
  - With increasing RF Frequencies and increasing RF bandwidths Direct Sampling wins.

- In all Cases please never forget to use an excellent RF Hardware.
- And don’t forget the user →he must be happy

Some References

- Ulrich L. Rohde, Jerry C. Whitaker and Hans Zahnd*, Communications Receivers: Principles and Design*, McGraw Hill, Fourth Edition, 2017.
- MIT, MTL Seminar Series - Problems and Solutions of HF/UHF Systems, May 7, 2024: https://www.mtl.mit.edu/events-seminars/seminars/problems-and-solutions-hfuhf-systems
- Ulrich L. Rohde, Thomas Boegl, "The Perfect HF Receiver. What would it look *Like Today?"* Microwave Journal May 2022
- Ulrich L. Rohde, Thomas Boegl, "The Perfect HF Receiver. What would it look *Like Today?"* IEEE MTT-S International Microwave Symposium, TH2B-1 Keynote
- Ulrich L. Rohde, Thomas Boegl, *"A modern HF/VHF/UHF Transceiver for all applications. How would it look like today?" Microwave Journal Oct. 2023*
- Thomas Boegl, Rohde & Schwarz, "*Test and Measurement for Radio Communication Equipment", 2019*
- Manfred Fleischmann, *"A Novel Technique to Improve the Spurious-free Dynamic Range of Digital Spectrum Monitoring Receivers",* Dissertation from 2022 at the Brandenburgische Technische Universität Cottbus-Senftenberg
- Ulrich L. Rohde, Mathias Rudolph, *RF/Microwave Circuit Design for Wireless Applications,* Wiley, second edition
- Ulrich L. Rohde, Microwave Receiver and Design Principles, SDR Wireless Innovation Forum, Keynote March 2014
- Ulrich L. Rohde, *Theory of Intermodulation and Reciprocal Mixing, Practice, Definitions and Measurements in Devices and Systems, Part 1,* Synergy Microwave Corporation, Dec 2001
- Hans L. Hartnagel, Rüdiger Quay, Ulrich L. Rohde, Mathias Rudolph, *Fundamentals of RF and Microwave Techniques and Technologies*, Springer
- Paul Denisowski (KO4LZ), "*The Rebirth of HF"* White Paper Rohde & Schwarz North America.
- GLOBAL MARKETS,GLOBAL TECHNOLOGY,AND GLOBAL STUDENTS? https://www.mtl.mit.edu/sites/default/files/media/documents/2025/global-education-solution-munnich2025_4.pdf

PART 2

1. A CLOSER LOOK TO ADCs AND WHAT WE CAN ACHIEVE HERE.
2. PLACING AN ADC INTO A RECEIVERS BLOCK DIAGRAM

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WHAT IS IMPORTANT AT THE VERY BEGINNING:

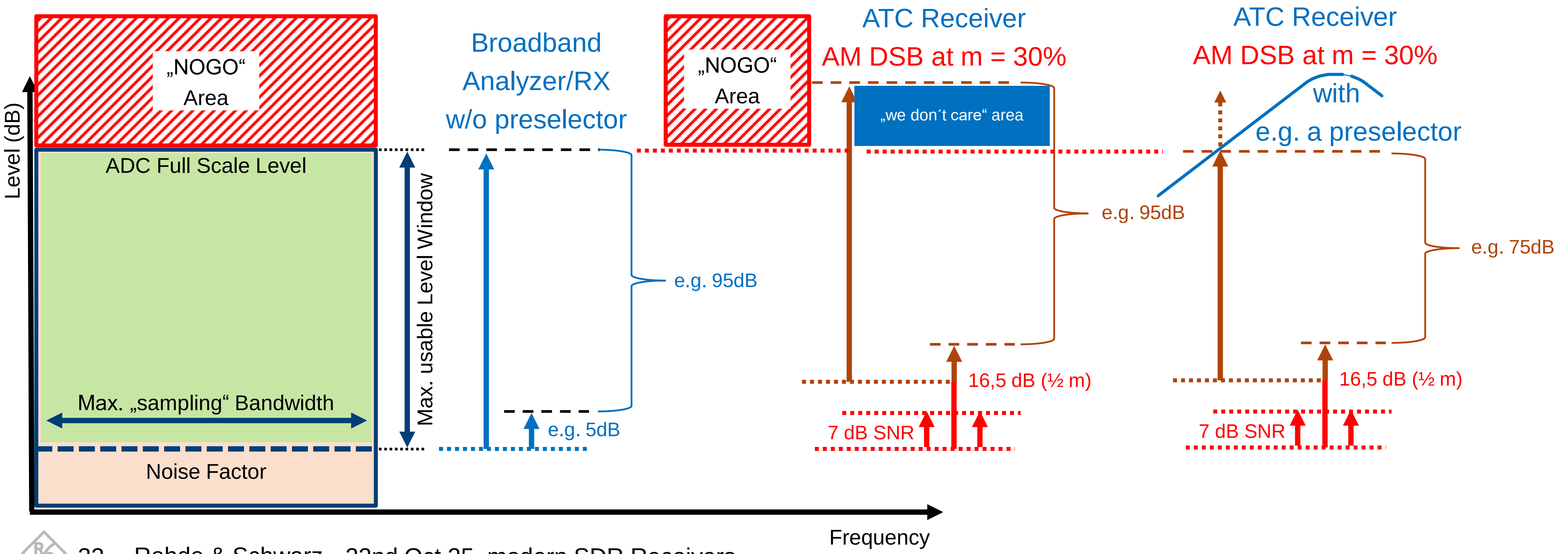
- Let´s look to these Questions now:
  - *I want to build a particular SDR equipment* → *What ADC/DAC do I need for that ?*
  - *I have a particular ADC/DAC* → *What SDR equipment can a I built with it?*
- For both it is necessary to know where ADCs and DACs are used within an SDR Design (transceiver)
- So let´s start first with a short look to ADCs
- And then we built some typical SDR receiver block diagrams

WHAT WILL (CAN OR SHOULD) AN ADC SEE AT ITS INPUT?

- And again another Question:
  - What is the “maximum mix of signals” we can directly operate with an ADC?

ADCs Operating Window

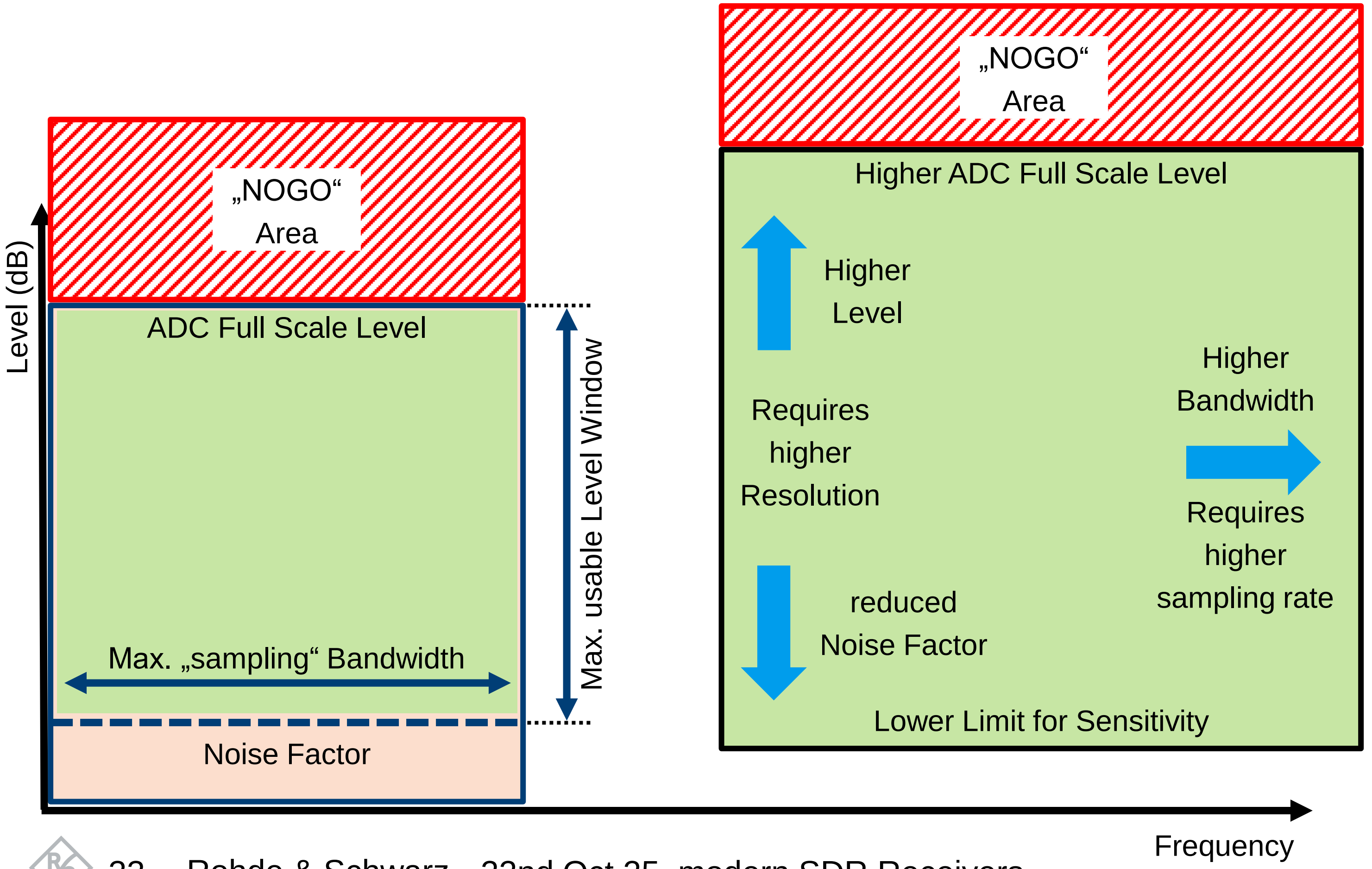
- Lets now place some signals into this window → e.g. a data sheet says 95 dB Dynamic Range:



WHAT WILL (CAN OR SHOULD) AN ADC SEE AT ITS INPUT?

- Let´s look to this Questions now:
  - What can we do to “increase” the operating window of the ADC?

ADCs Operating Window



Where do we set the entry point for the NOGO Area?

This point is different if the receiver is operated at an antenna or “just at a D.U.T.”

→ Let´s look why

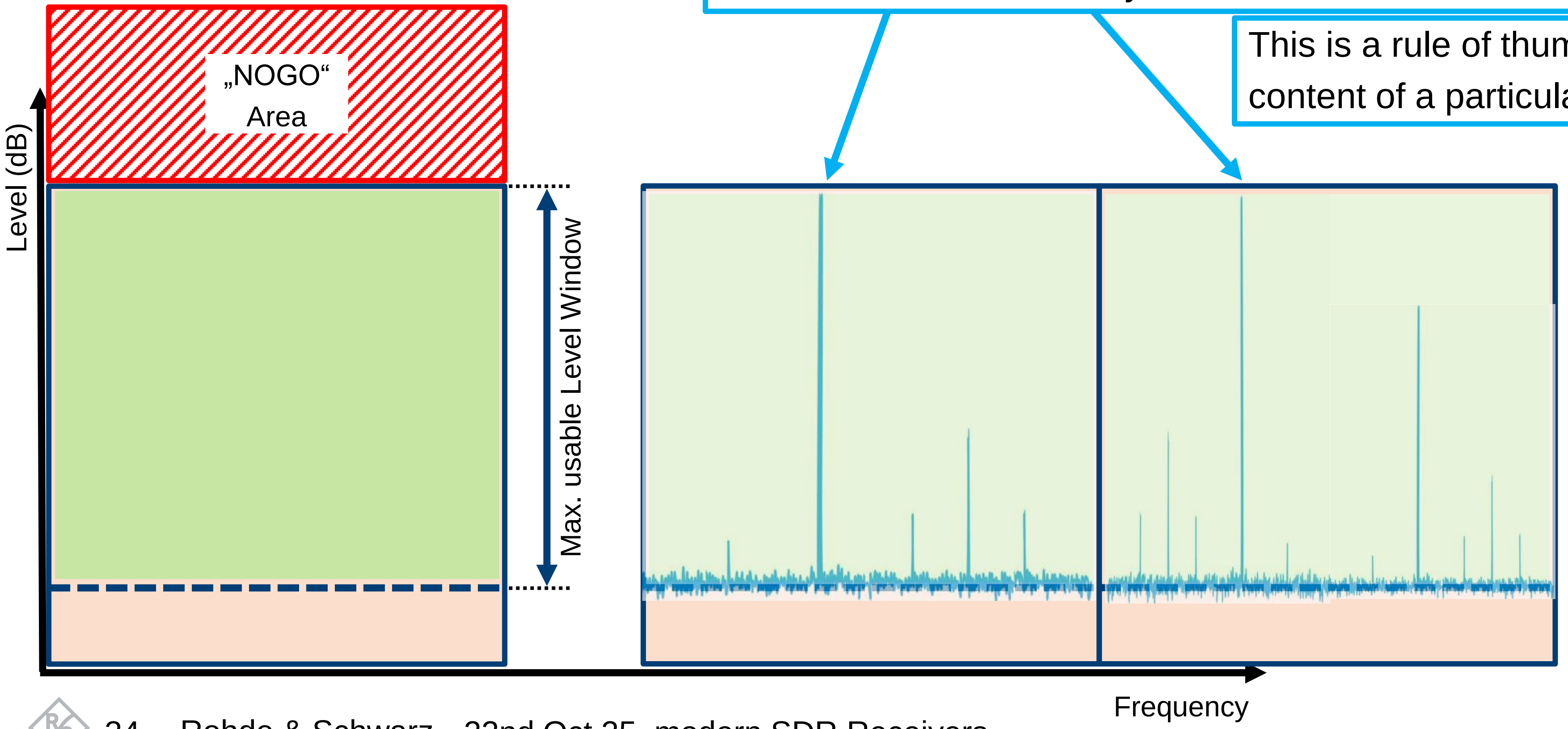
WHAT WILL (CAN OR SHOULD) AN ADC SEE AT ITS INPUT?

- Let´s look to this Questions now:
  - What happens if we increase the operating window of the ADC operated at an antenna?
  - Lets double the bandwidth

ADCs Operating Window

If we are increasing the instantaneous bandwidth of a receiver operated at an antenna (e.g. ultra broadband monitoring receiver) we must expect that the number of interferers is increased in the same way.

This is a rule of thumb because nowbody knows the exact content of a particular monitored bandwidth.



Lift up the „NOGO“ Area by xy dB

Set a backoff of xy dB

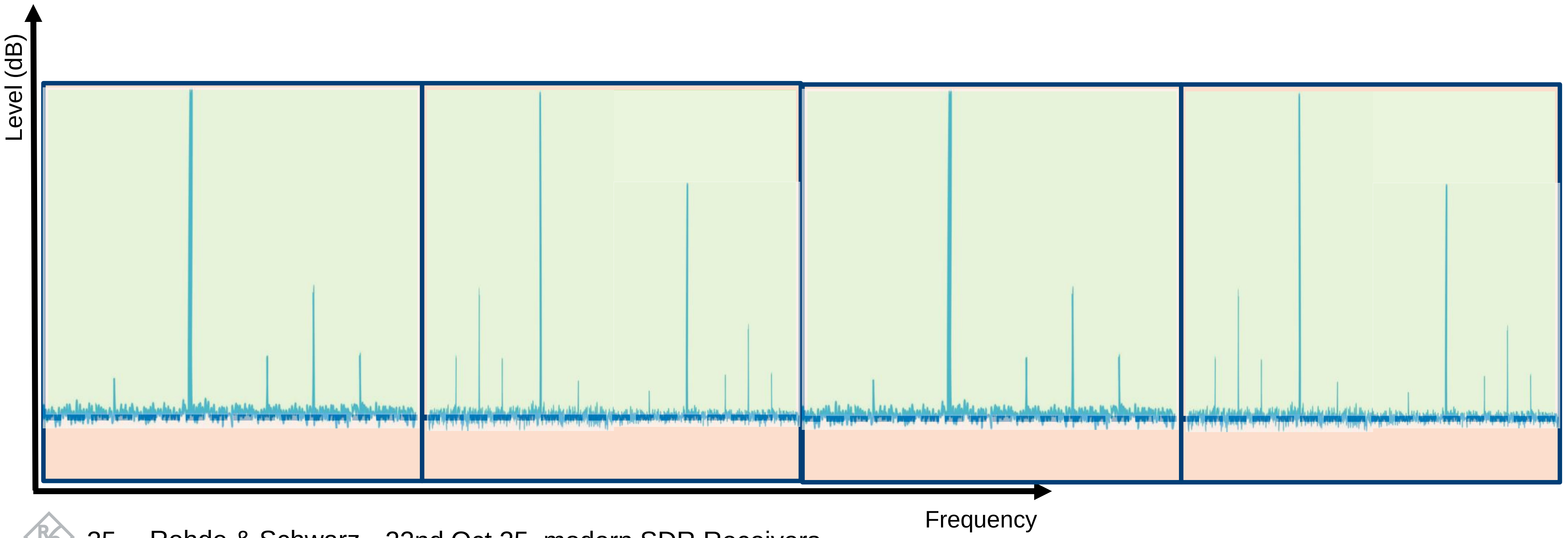
xy dB = 20 * log (increase of bandwidth)

It either requires an increase of the maximum allowed level or a backoff.

This is one of several challenges for a broadband receiver which wants to increase the bandwidth at the ADC because it also has to provide a higher resolution in parallel.

BUILDING AN ULTRA WIDEBAND RECEIVER

► It may be best for an ultra wideband receiver to couple “medium wideband” receivers to achieve a required dynamic range in combination with detection probability for short pulses



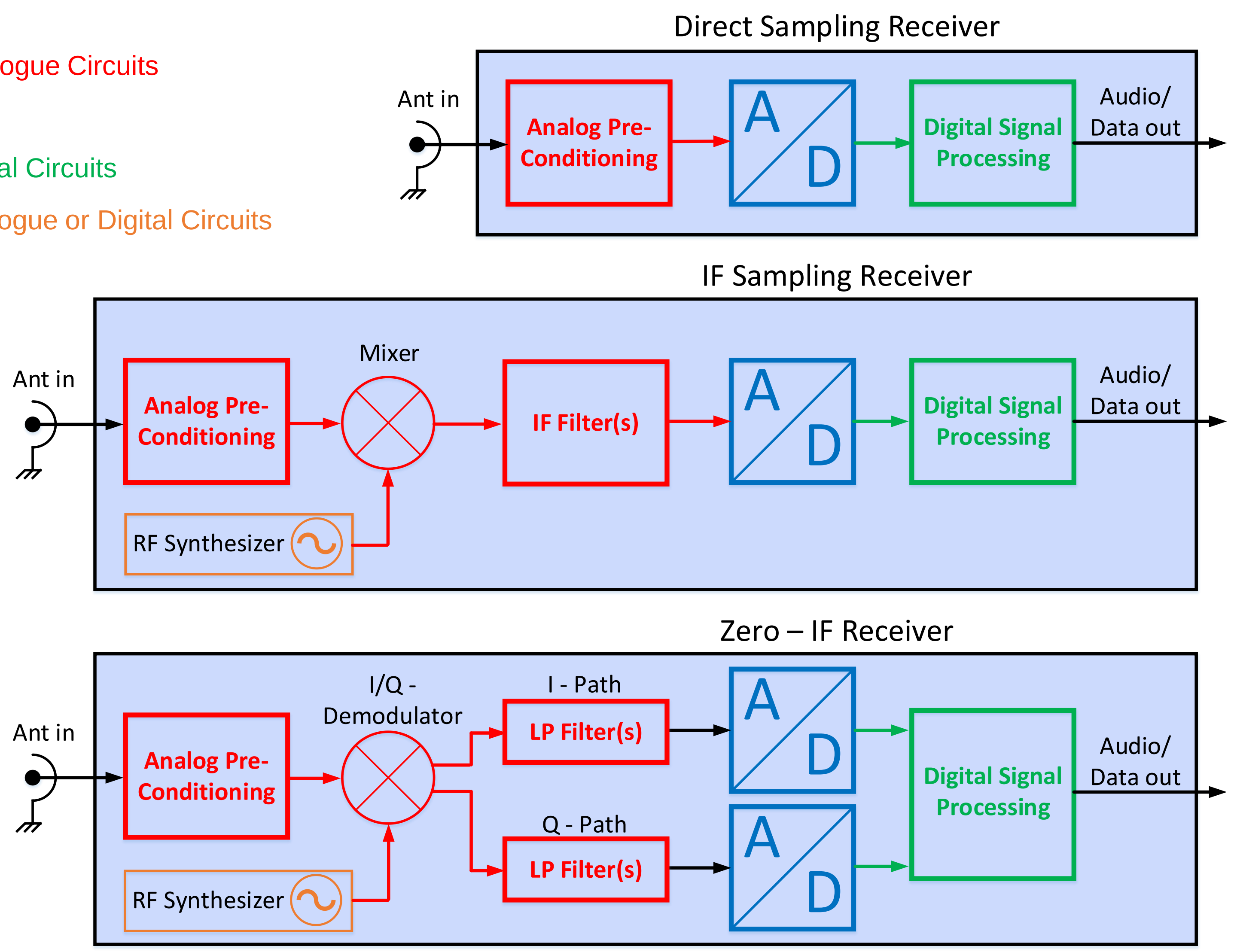
TYPICAL SDR BLOCK DIAGRAMS → RECEIVER

Analogue Circuits

ADC

Digital Circuits

Analogue or Digital Circuits



Required „Quality“ of ADC

high, very high up to unsolvable

moderate, low, down to very low

moderate, low, down to very low

NOW WE FOCUS ON ADCs AND DACs

► The current market leaders for ADC and DAC are:

– AMD

– Texas Instruments

– Analog Devices

NOW WE FOCUS ON ADCs AND DACs - AMD

- ► ZYNC Ultrascale+ FPGA with RF System on a Chip
  - – 2/4/8/16 ADC 12/14 Bit 2.5/5 GSPS
  - – 4/8/12/16 DAC 14 Bit 6/10 GSPS
  - – Integrated DDC and DUC
- ► VERSALTM RF Series
  - – RF input frequency up to 18 GHz
  - – 14-bit resolution with calibration
  - – 8 GSPS and 32 GSPS RF-ADC tiles
  - – RF output frequency up to 18 GHz
  - – 14-bit resolution with calibration
  - – 16 GSPS sample rate

NOW WE FOCUS ON ADCs AND DACs – TEXAS INSTRUMENTS

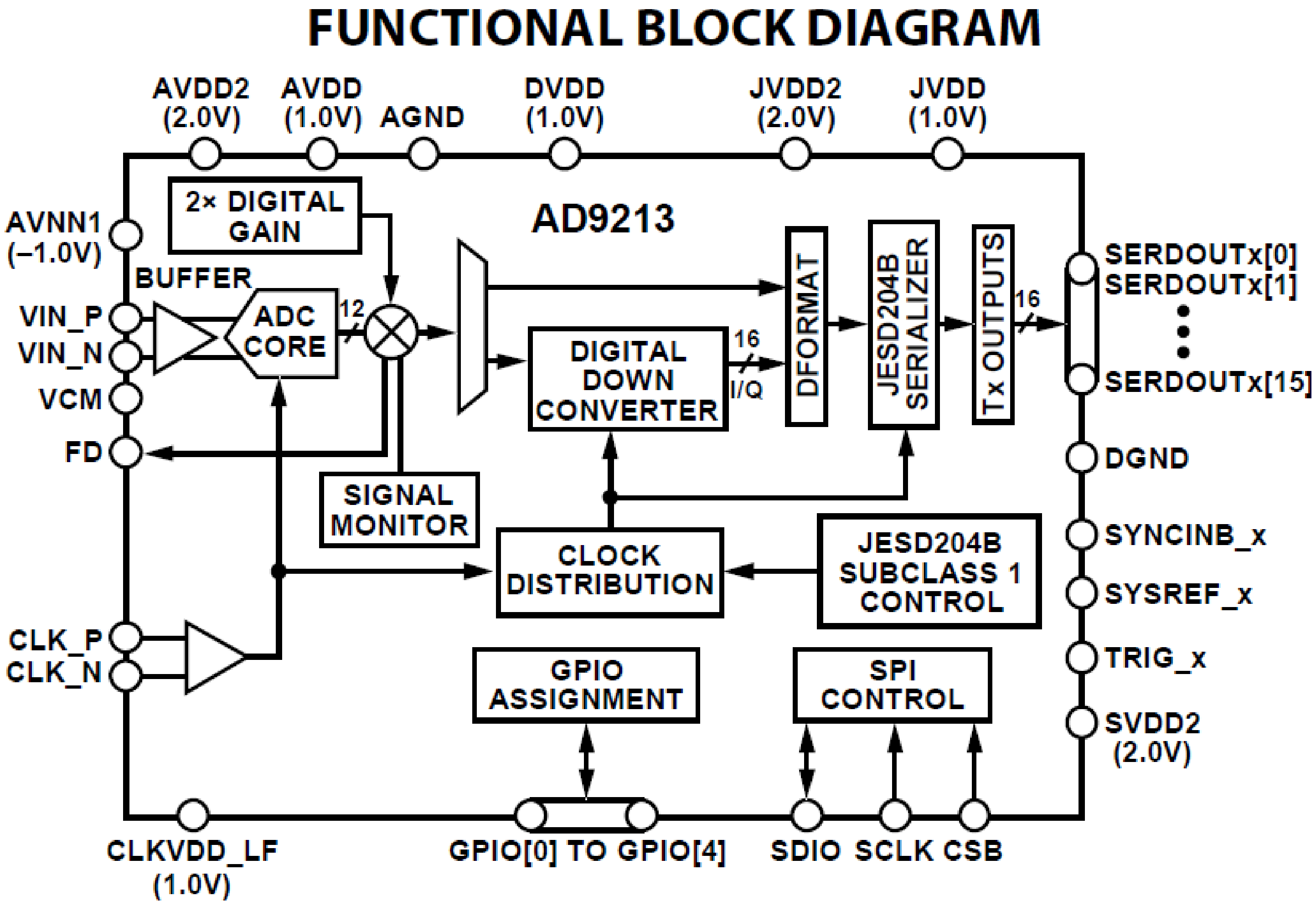
- Analog Frontend 6 ADC, 4 DAC, 12 GSPS, 1-12 GHz BW, max 1.2 GHz IBW
  Additional Analog Stages, AGC, TX Linearization
- High Performance ADC 2/4 CH, 3 GSPS,14 Bit, 2.3 GHZ BW, 1.2 GHZ IBW
  NSD -161 dBFS/Hz, SFDR 90 dB
- Wideband DAC 2 CH, 12 GSPS,16 Bit, 12 GHz OBW, Multi-Nyquist
- Wideband ADC 10 GSPS, 12 Bit, DC-8 GHz BW
- Integrated DDC and DUC

NOW WE FOCUS ON ADCs AND DACs – ANALOG DEVICES

► Analog Devices:
  - System on Chip (SoC) RF agile transceiver with integrated digital front end (DFE) ADC, DAC max 500 MSPS, 400 MHz IBW, Digital Predistortion (DPE)
  - Wideband Mixed Signal Frontend, DAC, 16-Bit, 28 GSPS, ADC, 12-Bit, 20 GSPS max Analog BW 18 GHz
  - 4 Wideband DAC, 16-Bit, 12 GSPS, 8 DUC, Complex Signal Generator
  - Low Power ADC, 12-Bit, 10 GSPS, 4 W, NSD -155 dBFS/Hz, SFDR 70 dB SNR 55 dB

ANALOG DEVICES
AHEAD OF WHAT'S POSSIBLE™

AN ADC "CHIP" IS NOT JUST AN ADC – ITS MUCH MORE



- An ADC Chip incorporates some more building blocks – not just the ADC itself

Applications that require less instantaneous bandwidth can benefit from the on-chip, digital signal processing (DSP) capability of the AD9213 that reduces the output data rate along with the number of JESD204B lanes required to support the device. The DSP path includes a digital downconverter (DDC) with a 48-bit, numerically controlled oscillator (NCO), followed by an I/Q digital decimator stage that allows selectable decimation rates that are factors of two or three. For fast frequency hopping applications, the AD9213 NCO supports up to 16 profile settings with a separate trigger input, allowing wide surveillance frequency coverage at a reduced JESD204B lane count.

The AD9213 supports sample accurate multichip synchronization that includes synchronization of the NCOs. The AD9213 is offered in a 192-ball ball grid array (BGA) package and is specified over a junction temperature range of –20°C to +115°C.

DIRECT RF FPGAS WITH ADCS/DACS

Features	AMD RFSoC	Altera Stratix 10	Altera AGRW014	Altera AGRW027	AMD Versal RF
Qty ADCs # of Bits Sample Rate Input IBW	8 14 5 GS/s 6 GHz	8 10 64 GS/s 36 GHz	4 10 64 GS/s 36 GHz	8 10 64 GS/s 36 GHz	8 14 32 GS/s 20 GHz
Qty DACs # of Bits Sample Rate	8 14 9.8 GS/s	8 10 64 GS/s	4 10 64 GS/s	8 10 64 GS/s	16 14 16 GS/s
Qty DDCs & DUCs	8	8	4	8	320 Channelizers
ARM Processors	Quad Cortex A53 Dual Cortex R5F	Quad Cortex A53	Quad Cortex A53	Quad Cortex A53	Dual Cortex 72 Dual Cortex R5F
AI Engines	0	0	0	0	120
Memory DSP Blocks Logic Cells Ethernet MACs	60.5 Mb 4272 930k 2x100G, 1x150G	244 Mb 5760 2800k 4x100G	190 Mb 4510 1400k 4x100G	287 Mb 8528 2700k 4x100G	189 Mb 3976 2473k 2x100G, 3x600G

Source:

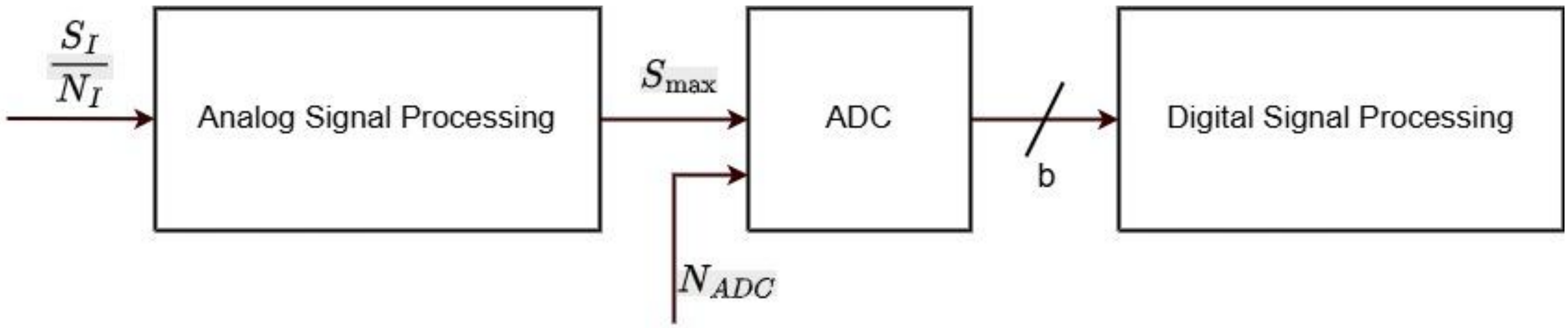
Rodger Hosking
Mercury Systems / Signal Technologies

IEEE New Jersey Chapter
39th Annual Symposium & Mini-Show
October 9, 2025

CHARACTERISITCS OF A DSP RECEIVER

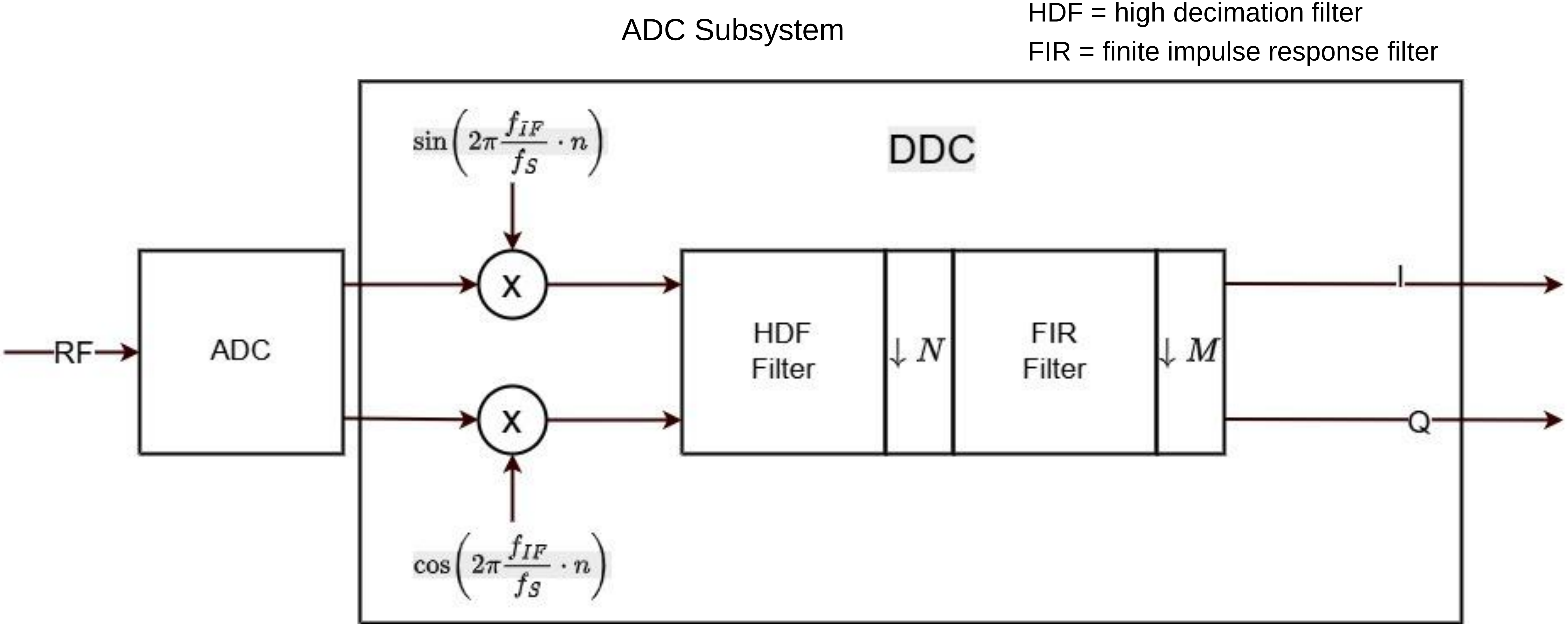
- A more detailed view to:
  - Utilization of the A/D converter dynamic range
  - Prevention of overloading of the A/D converter
  - The inherent noise of the analog signal processing predominates over the quantization noise of the A/D converter

BASIC BLOCK DIAGRAM OF AN SDR SIGNAL CHAIN

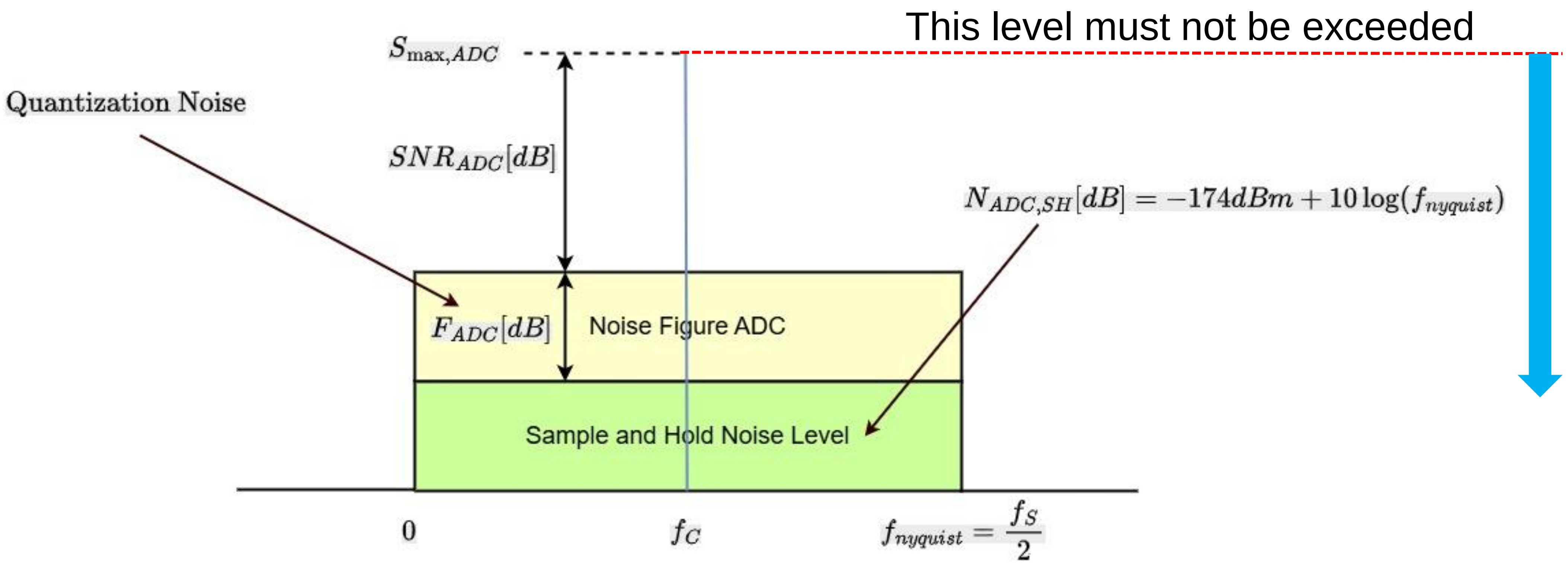


BASIC BLOCK DIAGRAM OF AN SDR RX SIGNAL CHAIN

DDC = digital downconversion
HDF = high decimation filter
FIR = finite impulse response filter



NOISE FIGURE OF AN ADC AND ITS DYNAMIC RANGE



Signal Processing Algorithms are basically diving down from S_{max} until they end within a noise floor which is not originated by the receive signal spectrum

NOISE FIGURE OF AN ADC AND USABLE DYNAMIC RANGE
NOISE FIGURE OF THE ADC

The noise figure of an A/D converter is the difference of the signal-to-noise ratio between sampling stage and the signal-to-noise ratio of the digitized signal

Example AD9213S-CSH (12-Bit 10 GSPS):

$S_{max,ADC}$ = +7 dBm (1.4 Vpp into 50 Ω) (Datasheet)

SNR_{ADC} = 55 dB (Datasheet)

$f_{nyquist}$ = 5 GHz (Datasheet)

$SNR_{ADC} = S_{max,ADC} - (-174\ dBm + 10\log(f_{nyquist})) - F_{ADC}$

$F_{ADC} = S_{max,ADC} - SNR_{ADC} + 174\ dBm - 10\log(f_{nyquist})$

$F_{ADC} = (7 - 55 + 174 - 97)\ dB = 29\ dB$

5 GHz = 5 * 10^9 Hz → 97 dB more than 1 Hz

The thermal noise floor power (densitiy) at room temperature is -174 dBm per 1 Hz Bandwidth

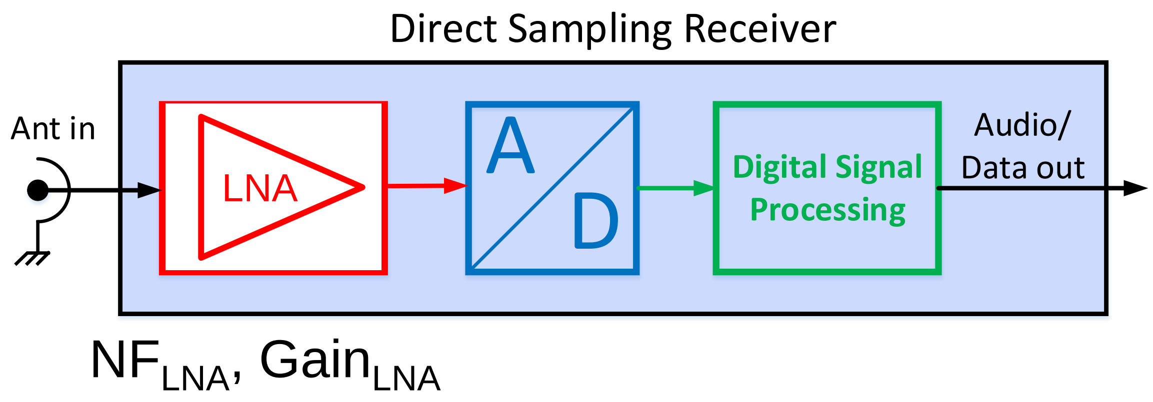
These are the limiting boundaries we are always ending on

This means that we can “play” now with bandwidth and gain to optimize our design

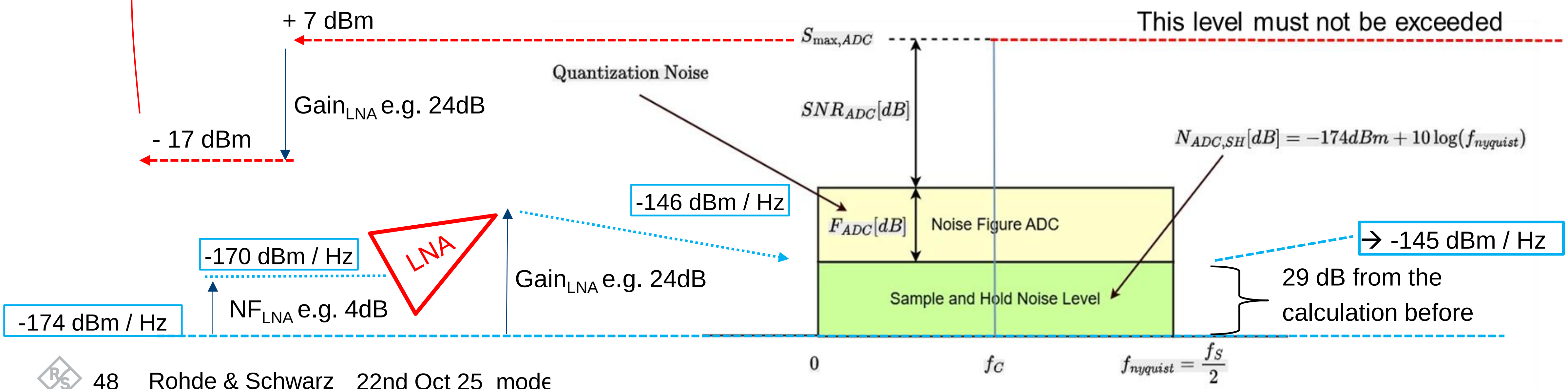
FINDING THE RIGHT GAIN FOR THE RECEIVER CHAIN

INTERIM CONSIDERATIONS FOR A WIDEBAND DIRECT SAMPLING RECEIVER

Max allowed total Interferer Level at Antenna Input



With this level plan we have build an SDR with a Noise factor of 7dB using an LNA with 4 dB noise factor



FINDING THE RIGHT SENSITIVITY FOR THE RECEIVER CHAIN
MINIMUM DETECTABLE / DISCERNABLE SIGNAL MDS AT THE ADC

Minimum detectable signal (MDS) of an A/D converter :

$MDS_{fS} = N_{ADC,SH}[dBm] + F_{ADC}[dBm] = -174dBm + 10\log(f_{nyquist}/[Hz])[dB] + F_{ADC}[dB]$

$MDS_{fS} = (-174 + 97 + 29)$ dBm = -48 dBm

This was with our 5 GHz Bandwidth and we can detect - 48 dBm signals which is 55 dB lower than the max signal of + 7dBm

Sample rate reduction reduces quantization noise,

this reduces the MDS by the process gain :

$MDS_{fS,red} = N_{ADC,SH}[dBm] + F_{ADC}[dB] - 10\log(f_S/f_{S,red})[dB]$

$MDS_{fS,red} = -174dBm + 10\log(f_{nyq}/[Hz])[dB] + F_{ADC}[dB] - 10\log(f_S/f_{S,red})[dB]$

Now we are reducing the digital bandwidth relative to 5 GHz. In this example down to 32 kHz which is 52 dB lower

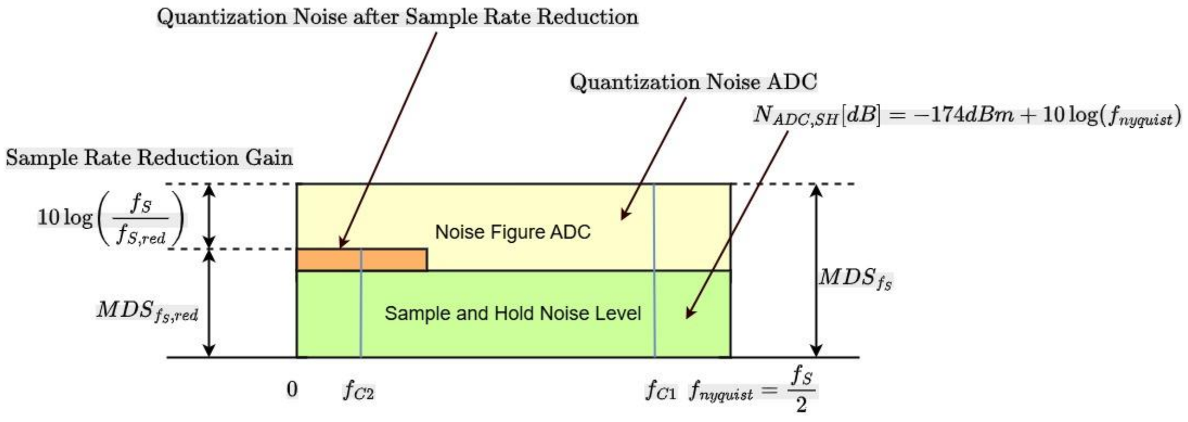
Assuming $f_{S,red}$ = 32 kS yields:

$MDS_{fS,red} = (-174 + 97 + 29 - 52)$ dBm = -100 dBm

Referenced to receiver input :

$MDS_{RX} = (-100 - 24)$ dBm = -124 dBm

With an LNA of e.g. 24 dB gain in front of the ADC the receiver will hear this signal



DYNAMIC BEHAVIOUR OF OUR SDR RECEIVER

DSP can achieve almost any filter characteristics when the ADC operates in the linear range.

We define an SSB signal with SNR = 10 dB and we are using an LNA with 24 dB Gain.

Question: What power can an interfering signal exhibit that can be reliably filtered out with DSP?

$S_{interferer} = S_{max} – g_{analog}$

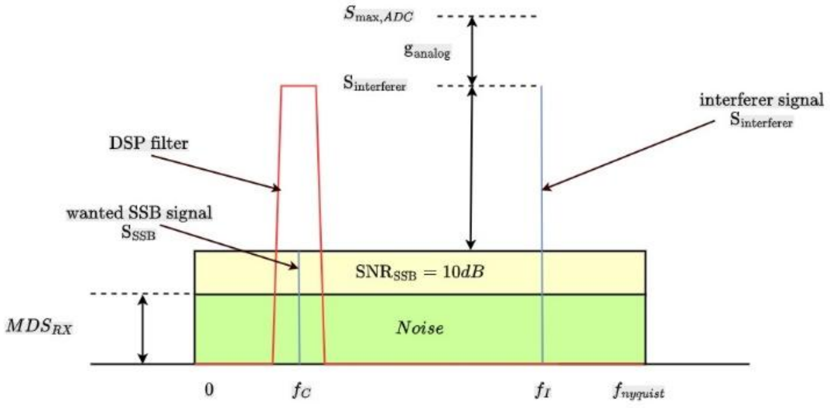
$S_{SSB} = MDS_{RX} + SNR_{SSB}$

$S_{interferer}$ = 7 dBm – 24 dB = -17 dBm

S_{SSB} = -124 dBm + 10 dB = -114 dBm

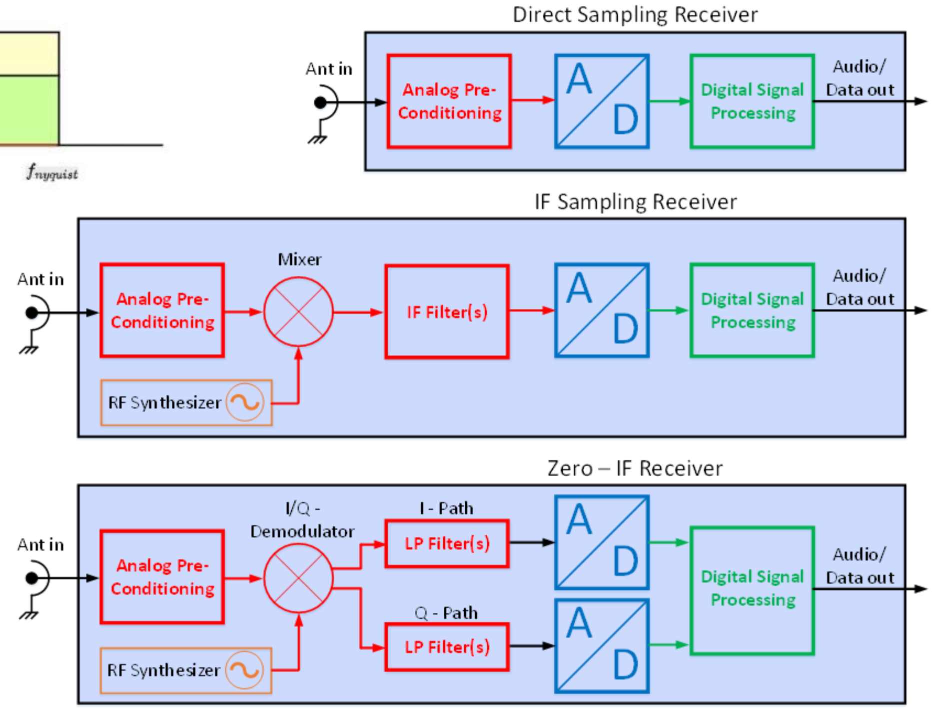
Static dynamic range of DSP receiver:

$S_{interferer} - S_{SSB}$ = -17 dBm + 114 dBm = 97 dB



Anything beyond that must be provided by analog filters

„somewhere“between Antenna and ADC



SOME REFERENCES

- Hans L. Hartnagel, Rüdiger Quay, Ulrich L. Rohde, Mathias Rudolph, *Fundamentals of RF and Microwave Techniques and Technologies*, Springer
- SDRA – Software Defined Radio Academy 2025, ADC - Analog Digital Converters and DAC - Digital Analog Converters, Their properties, state of the market and how to choose a suitable component for your project, Contribution to the Software Defined Radio Academy 2025, Tommy Valten DL4NW & Thomas Bögl DL9MDB - https://www.youtube.com/watch?v=0CepUaVqSeQ

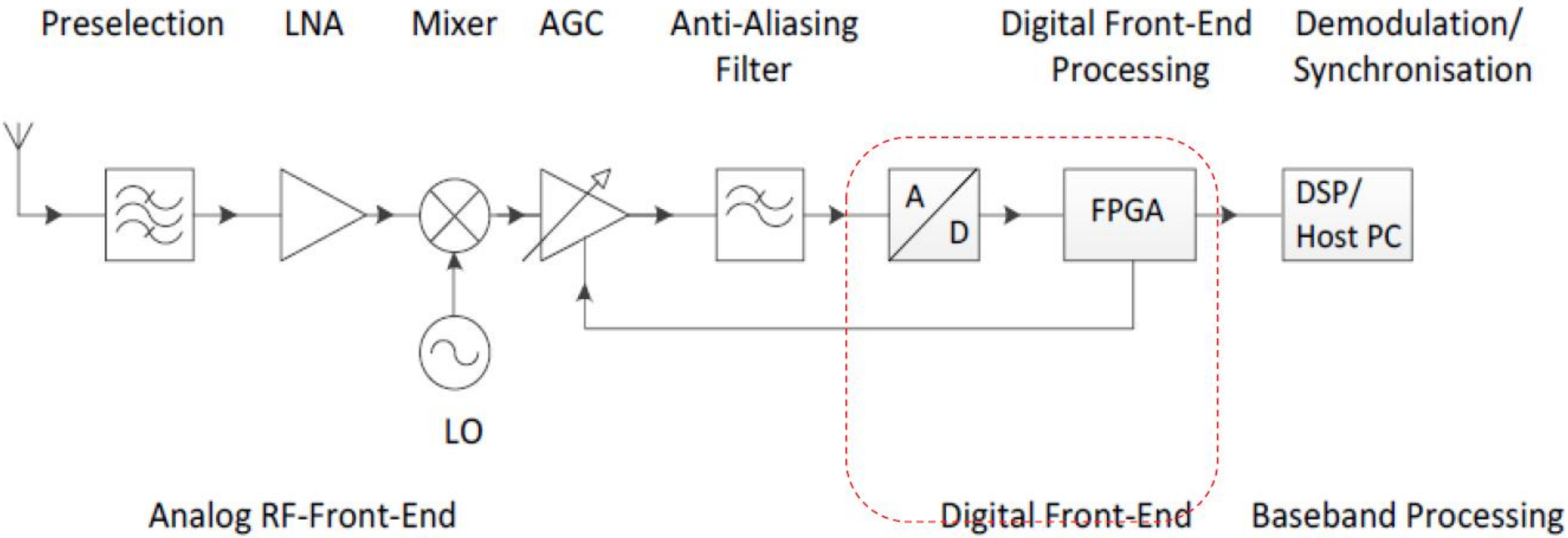
PART 3

1. Setting up an SDR Receiver Architecture
2. A more detailed look to some essential details

ROHDE&SCHWARZ

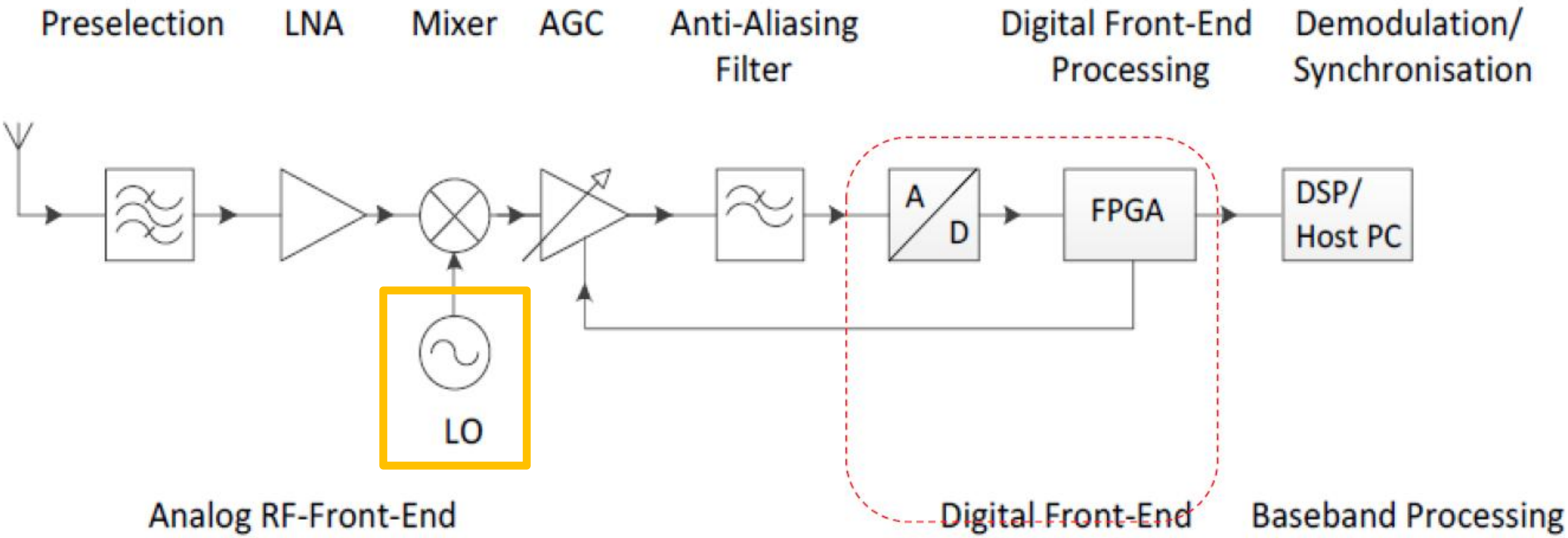
Make ideas real

A QUITE OFTEN USED BASIC ARCHITECTURE: SUPERHET



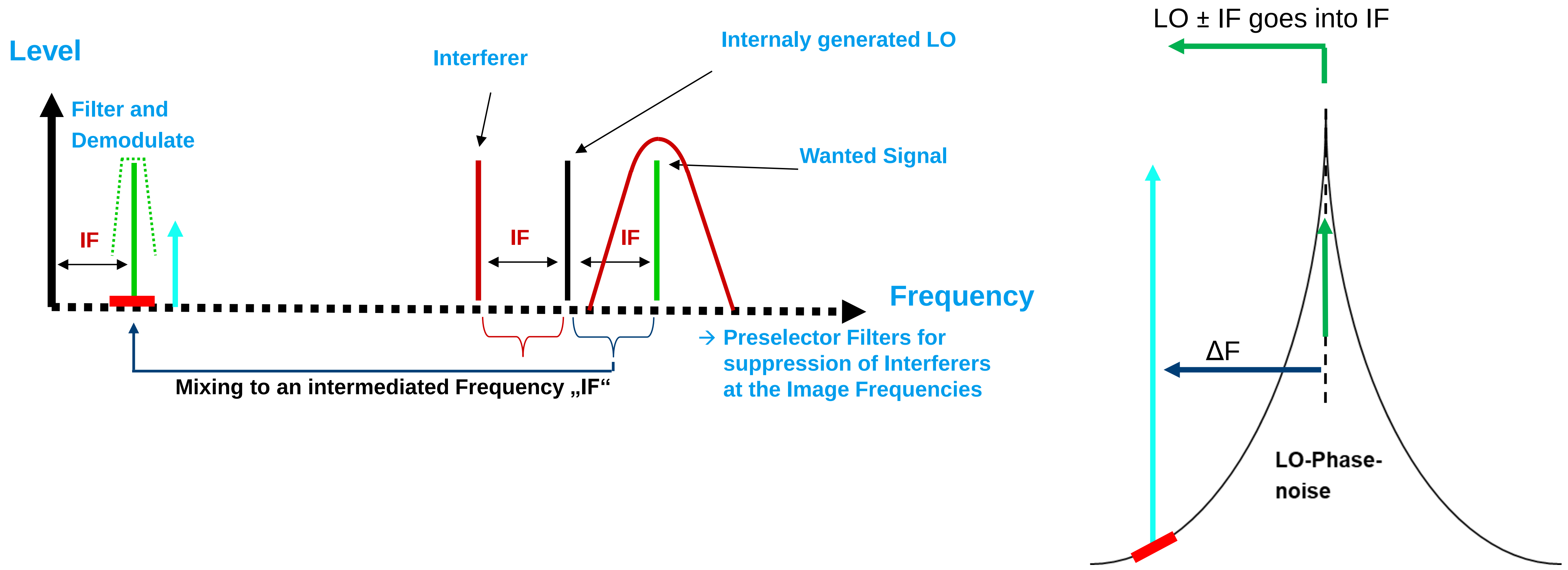
► **We are now picking out some essential parts**

A QUITE OFTEN USED BASIC ARCHITECTURE: SUPERHET



► **Relevance of Phase noise of the Local Oscillator LO**

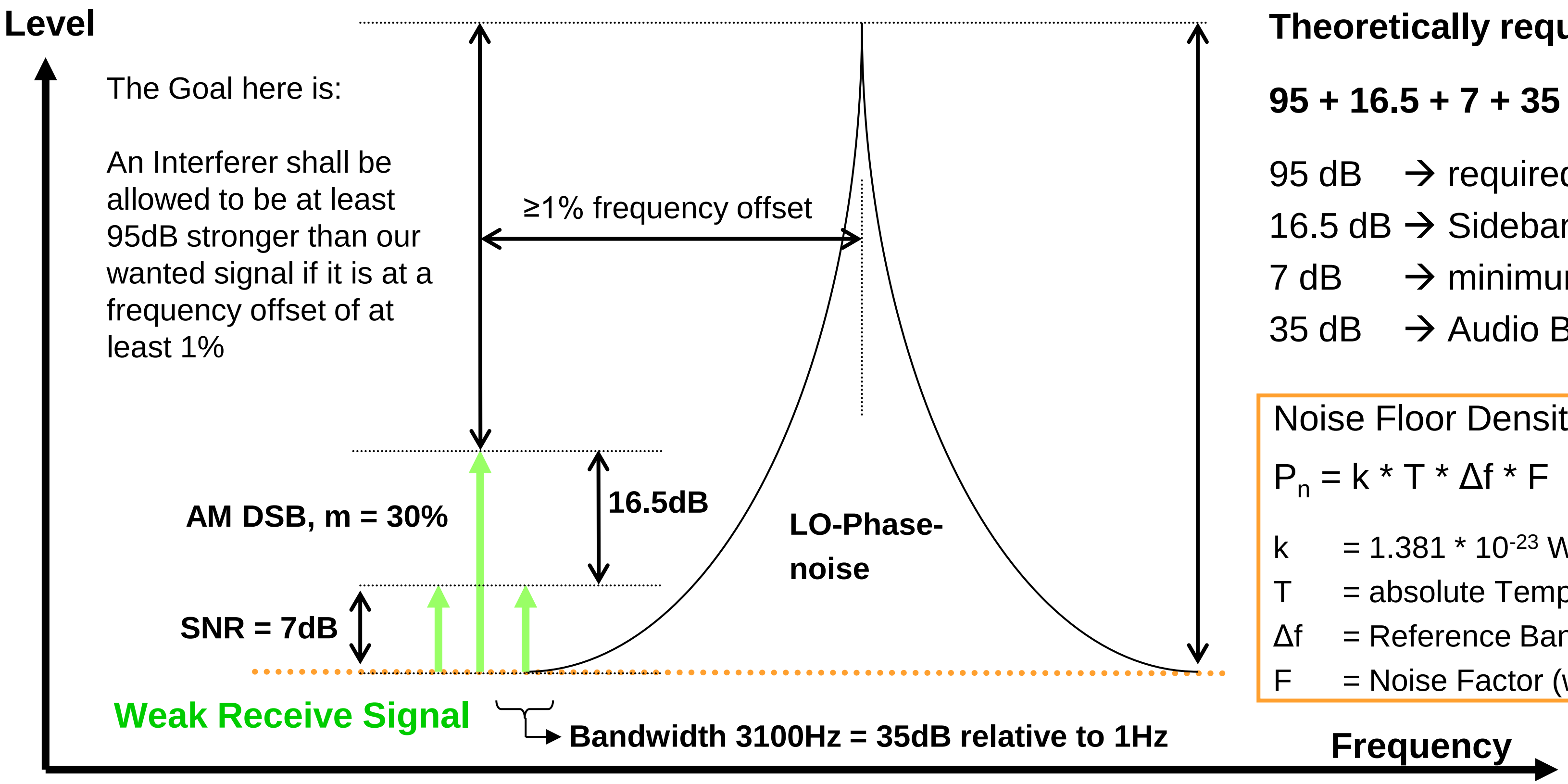
WHAT IS A SUPERHET ARCHITECTURE BASICALLY DOING?



- What happens if a strong interferer is very close (offset ΔF) to the receive channel?
- The noise energy of the LO in a distance of ΔF acts as low power LO
- As a consequence some noise appears in the background inside the IF
- This effect is called „reciprocal mixing“

DESENSITIZATION – AN INTERNAL MECHANISM

- The LO Phase Noise is mixing with a strong Interferer Level and is masking the wanted Signal
- This effect is called ***Reciprocal Mixing***
  - Any strong Interferer acts as "pseudo LO signal" and is mixing the LO Phase Noise into the Receiver Channel
- For this calculation example an analogue Voice AM DSB Signal with 30% Modulation is used



Theoretically required LO - Phase Noise @ 1% Offset

95 + 16.5 + 7 + 35 = 153.5dBc/Hz

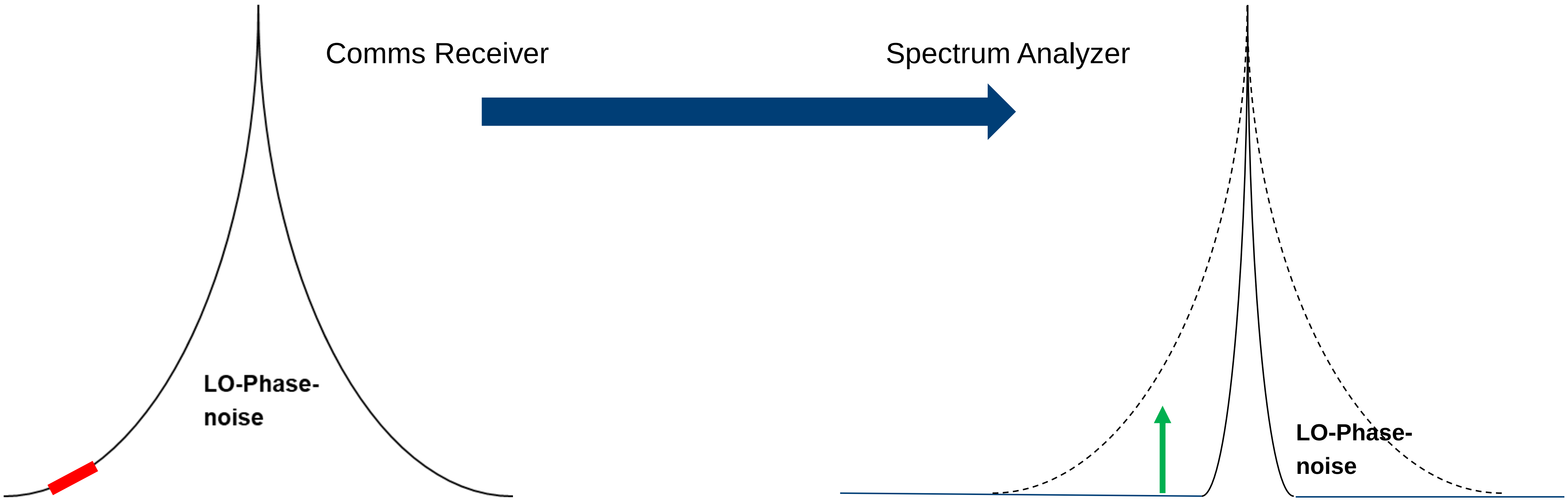
95 dB → required Desensitization (our design Goal)
16.5 dB → Sideband below Carrier (for AM DSB at m = 30%)
7 dB → minimum SNR left (minimum remaining Performance)
35 dB → Audio Bandwidth relative to 1Hz (for analogue Voice)

Noise Floor Densitiy P_n behind:

$P_n = k * T * \Delta f * F$ with

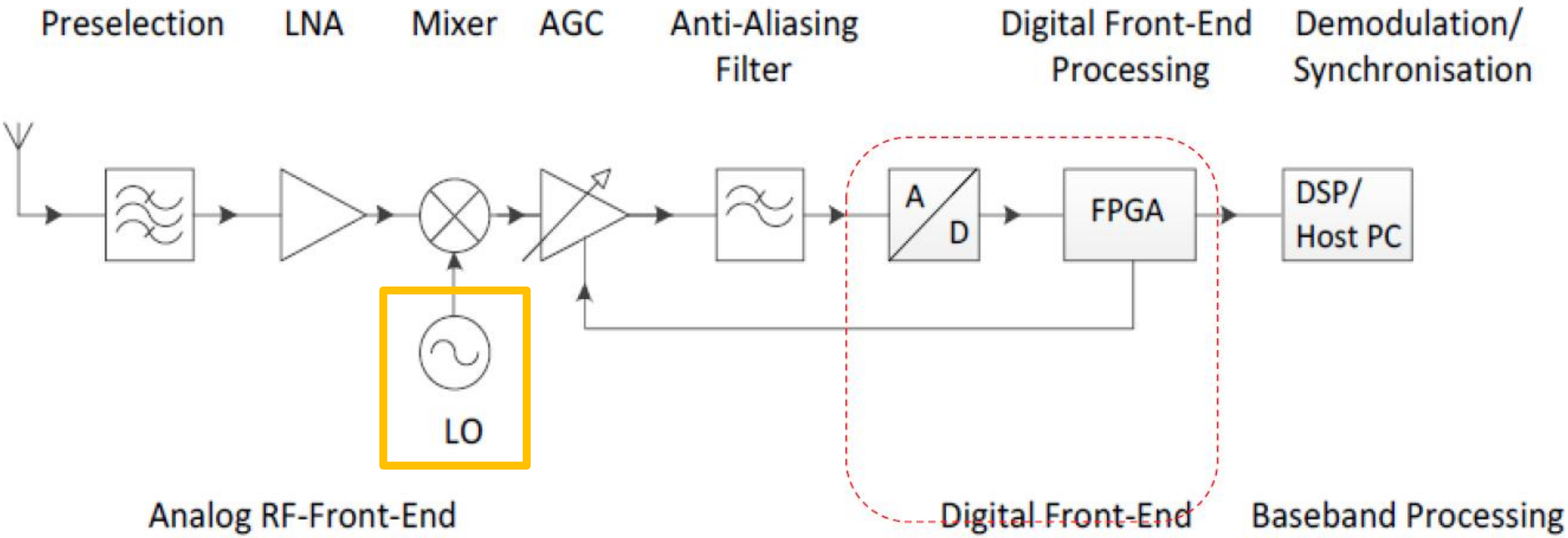
k = $1.381 * 10^{-23}$ Ws * K^{-1} (Boltzman Constant)
T = absolute Temperature
Δf = Reference Bandwidth (here we use 1Hz)
F = Noise Factor (within the IF or in Front of the ADC, not at the Antenna)

PHASE NOISE IMPORTANCE AND ITS IMPORTANCE
PRACTICAL RELEVANCE



- A Spectrum Analyzer needs a significantly better LO Phase Noise than a Comms Receiver
- Modern Synthesizers combine low noise analog Oscillators with DDS (Direct Digital Synthesis), Mixing, Frequency Division, Frequency multiplication and some more…..
- The complexity of the chosen solution should always represent the required practical need

A QUITE OFTEN USED BASIC ARCHITECTURE: SUPERHET

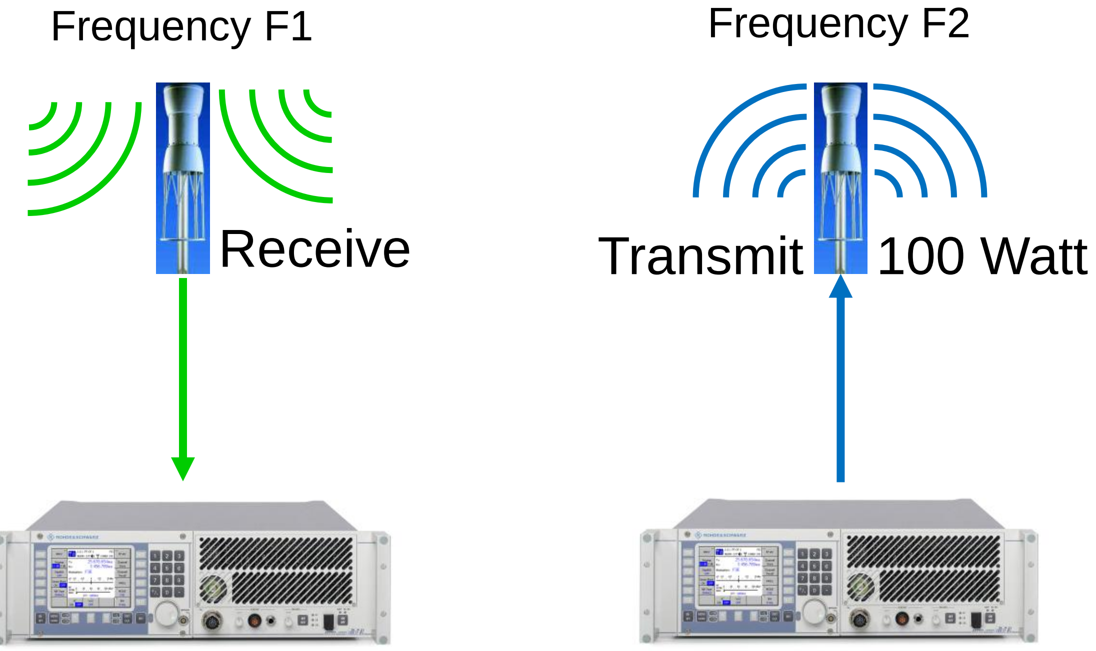


► **What is the practical Relevance of Phase noise of the Local Oscillator LO**

Use Case: SIMOP – Simultaneous Operation

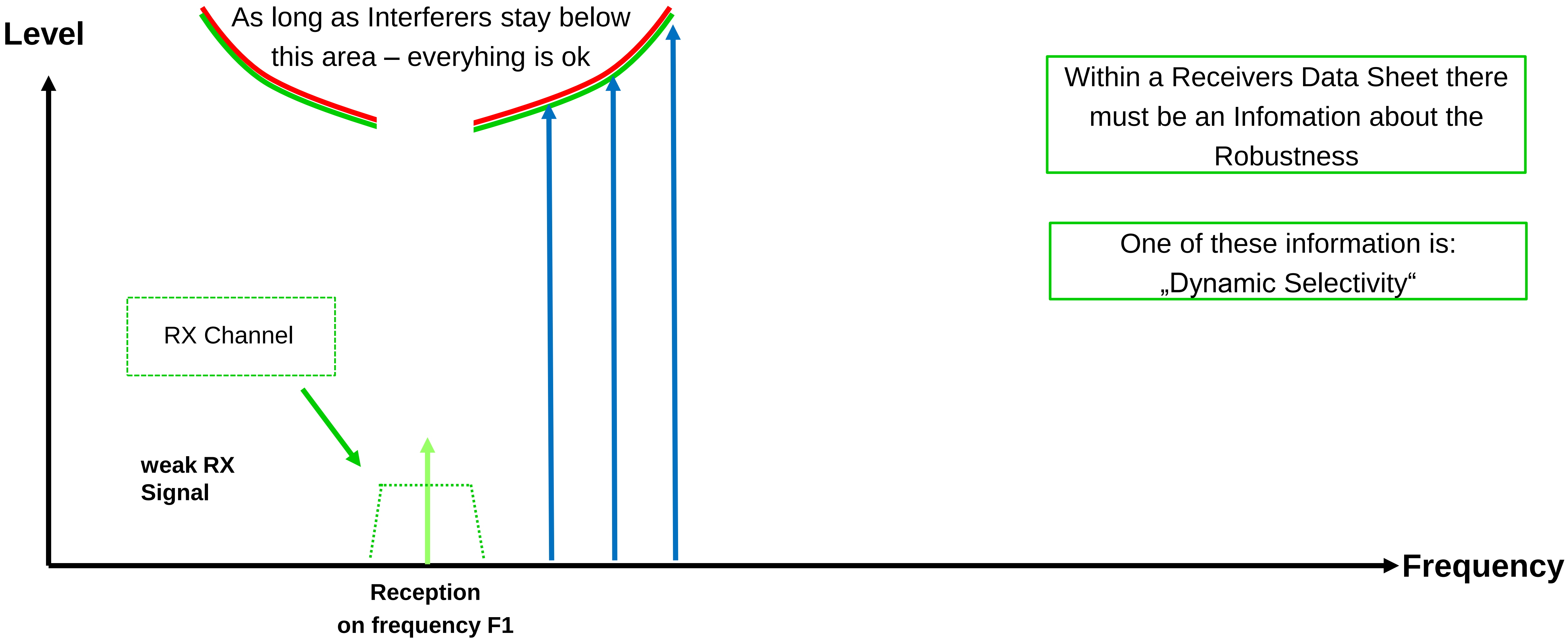
- A typical Ship - Installation uses approx. 10 – 15 V/UHF Radios.
- In all cases all Radios must work simultaneous and independent from each other:
  - 1 Radio transmits with 100 Watt (FM/CW) and alle others (N-1) are receiving
  - N-1 Radios are transmitting with 100 Watt (FM/CW) and one receives in parallel
  - No significant reduction of performance is allowed

  → 3dB Reduction of sensitivity is ok



Use Case: SIMOP – Simultaneous Operation

Dynamic Selectivity

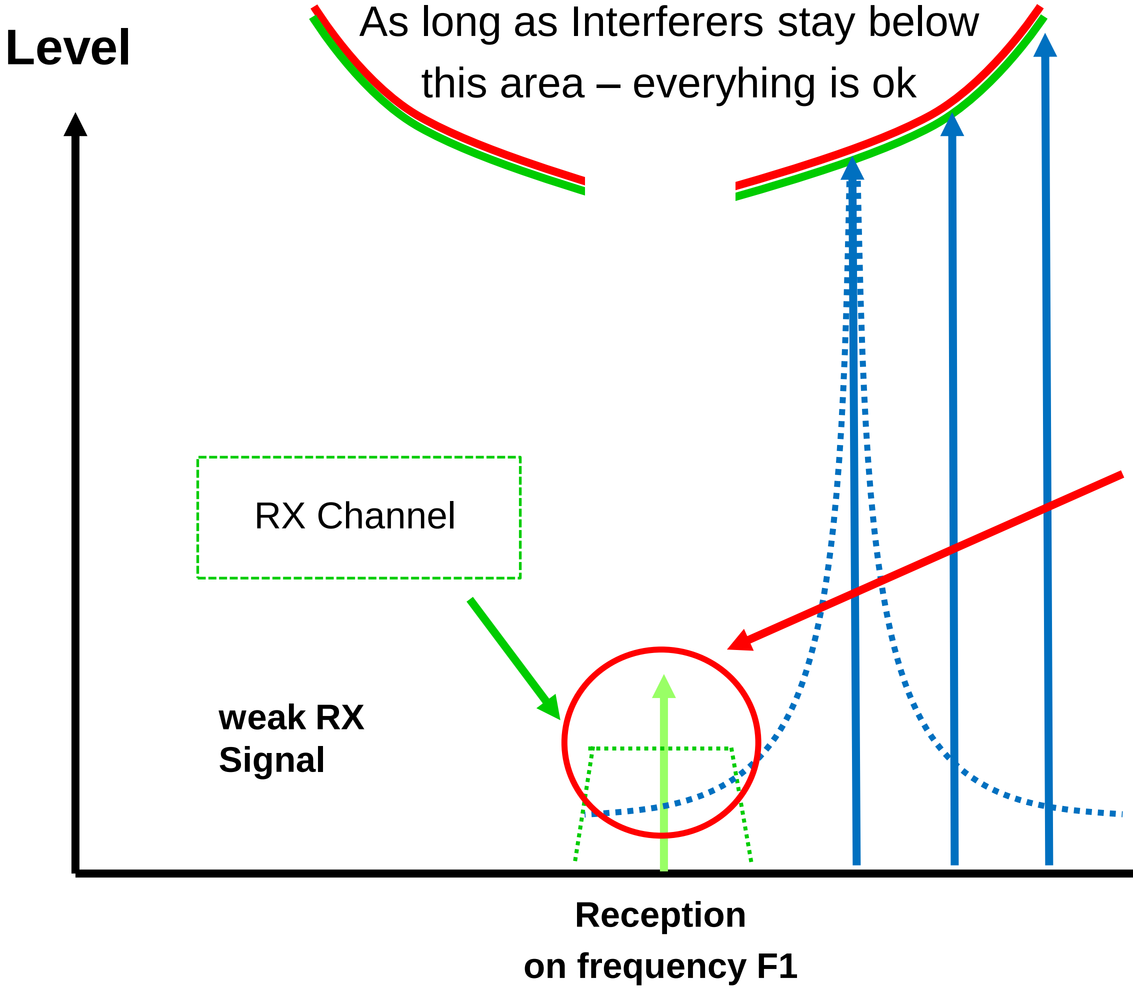


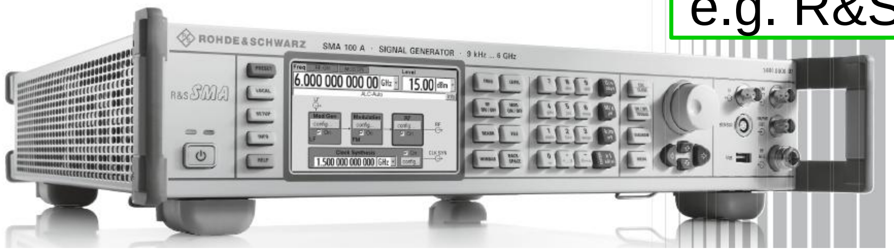
Within a Receivers Data Sheet there must be an Infomation about the Robustness

One of these information is: „Dynamic Selectivity“

Use Case: SIMOP – Simultaneous Operation

Dynamic Selectivity





e.g. R&S SMA100B

For this Measurement we need a Signalgenerator with excellent Phase Noise – otherwise it would negatively influence the Result

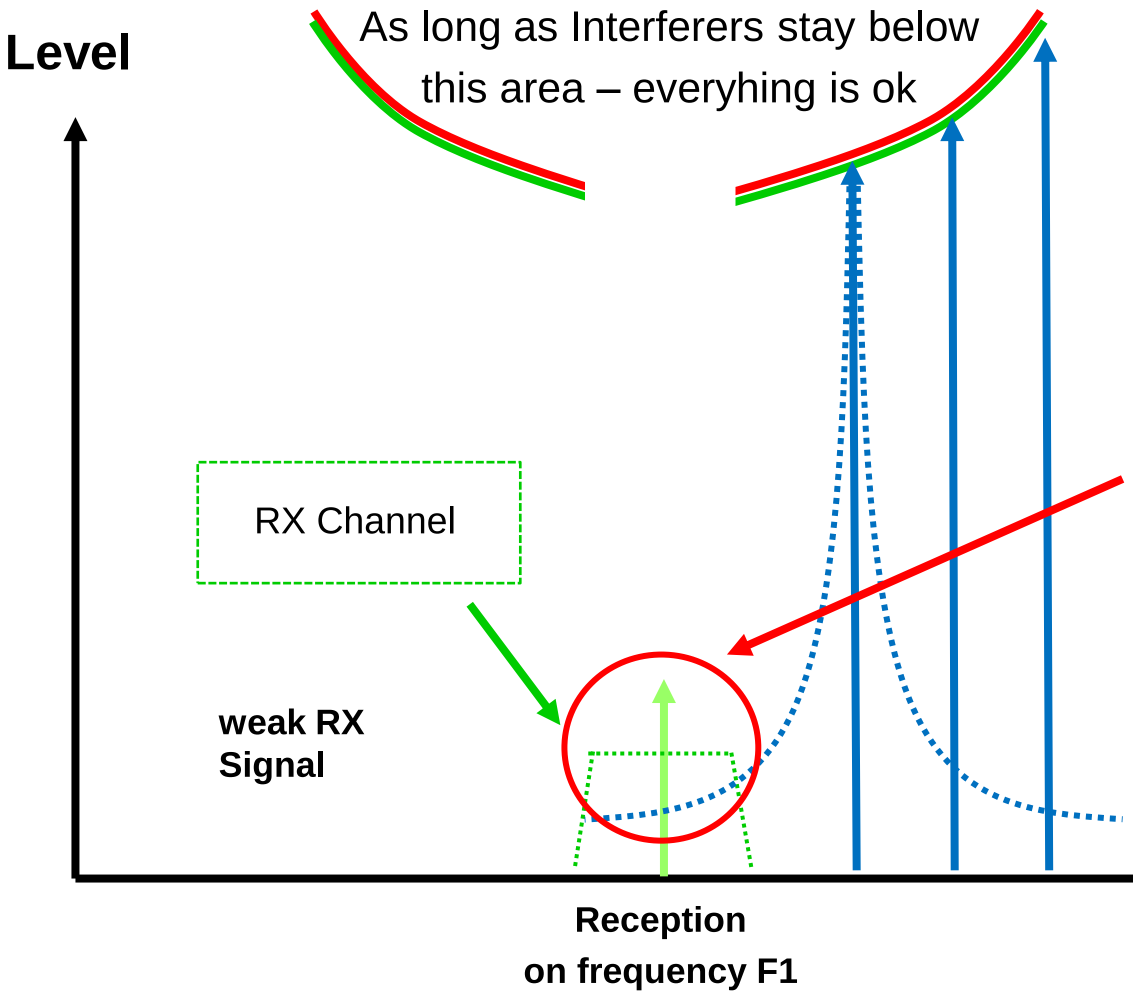
One of these Information is: „Dynamic Selectivity“

How can we measure it?

By applying an Interferer with a Signalgenerator and then checking how the Receiver reacts

Use Case: SIMOP – Simultaneous Operation

Dynamic Selectivity



The Value of „Dynamic Selectivity“ expresses, how much stronger an Interferer is allowed to be compared to a wanted Signal before a receiver starts to lose sensitivity
e.g. 80dB @ 25kHz says that an Interferer in 25kHz Distance can be at least 80dB stronger than a wanted Signal before a Receiver starts to react.

For this Measurement we need a Signalgenerator with excellent Phase Noise – otherwise it would negatively influence the Result

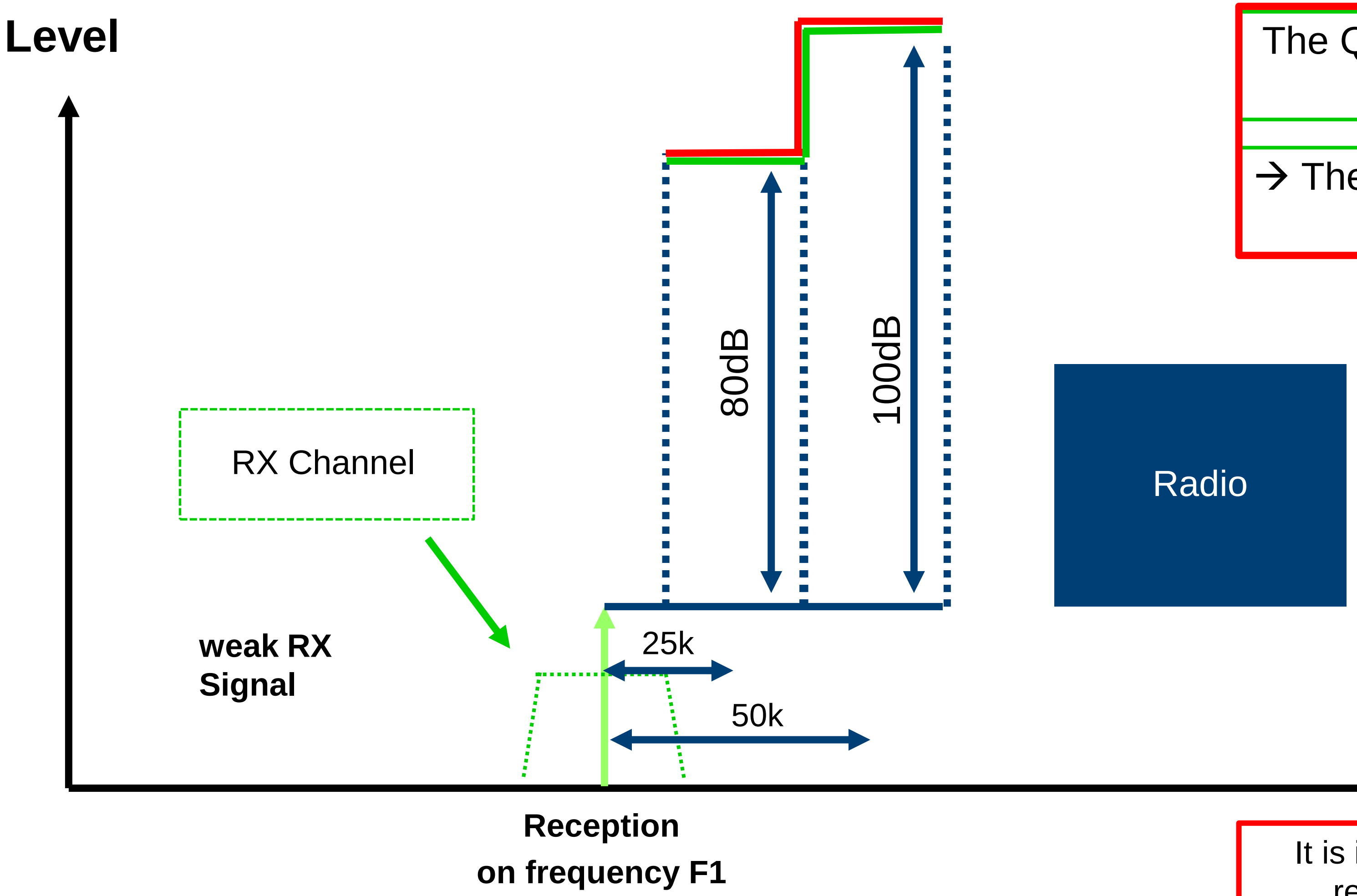
One of these Information is: „Dynamic Selectivity“

How can we measure it?

By applying an Interferer with a Signalgenerator and then checking how the Receiver reacts

Use Case: SIMOP – Simultaneous Operation

Dynamic Selectivity



The Question is now: which „Interferer“ to be taken as realistic Basis for the Design?

→ The Interferer is mostly the transmitter of another radio of the same type

Example: A radio program mandates for „Dynamic Seletivity“ the following:

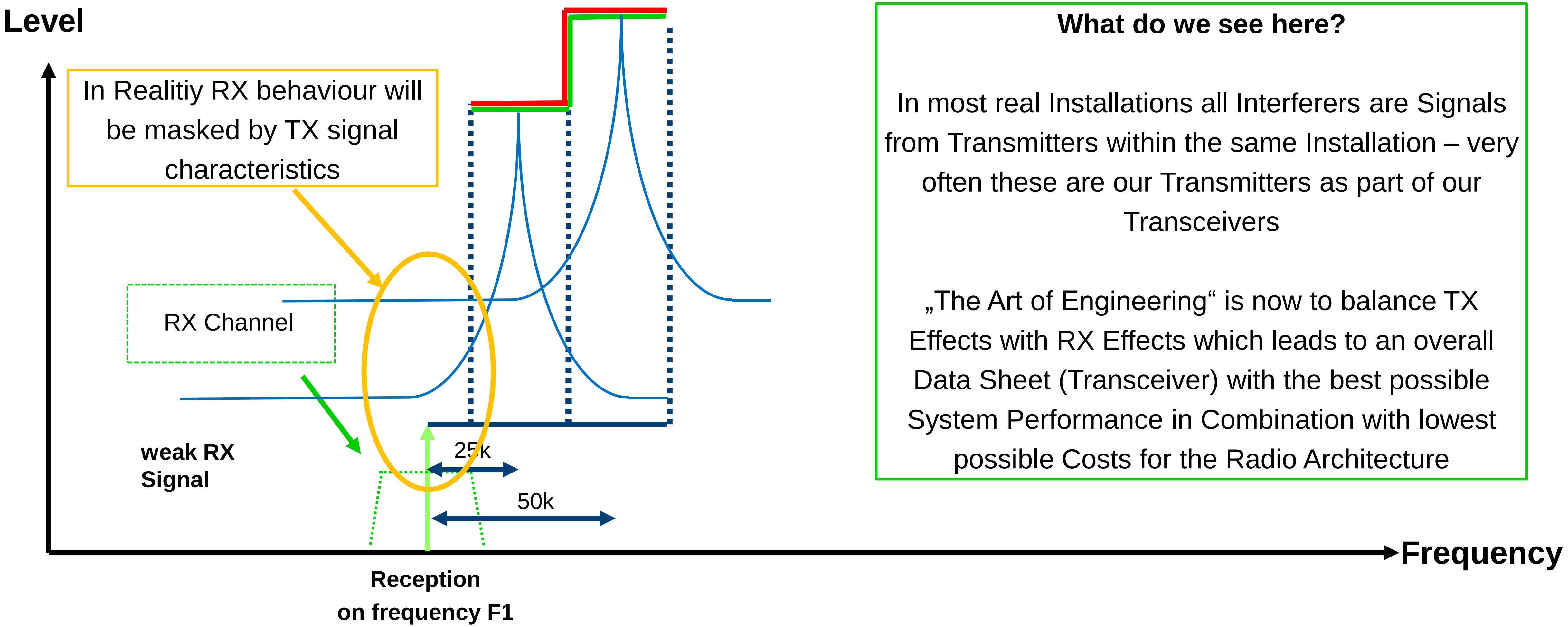
100dB @ 50kHz

80dB @ 25kHz

It is important to go from a „theoretical“ data sheet towards a realisitc data sheet. This will provide the same practical performance but allows simpler designs.

Use Case: SIMOP – Simultaneous Operation

Dynamic Selectivity



What do we see here?

In most real Installations all Interferers are Signals from Transmitters within the same Installation – very often these are our Transmitters as part of our Transceivers

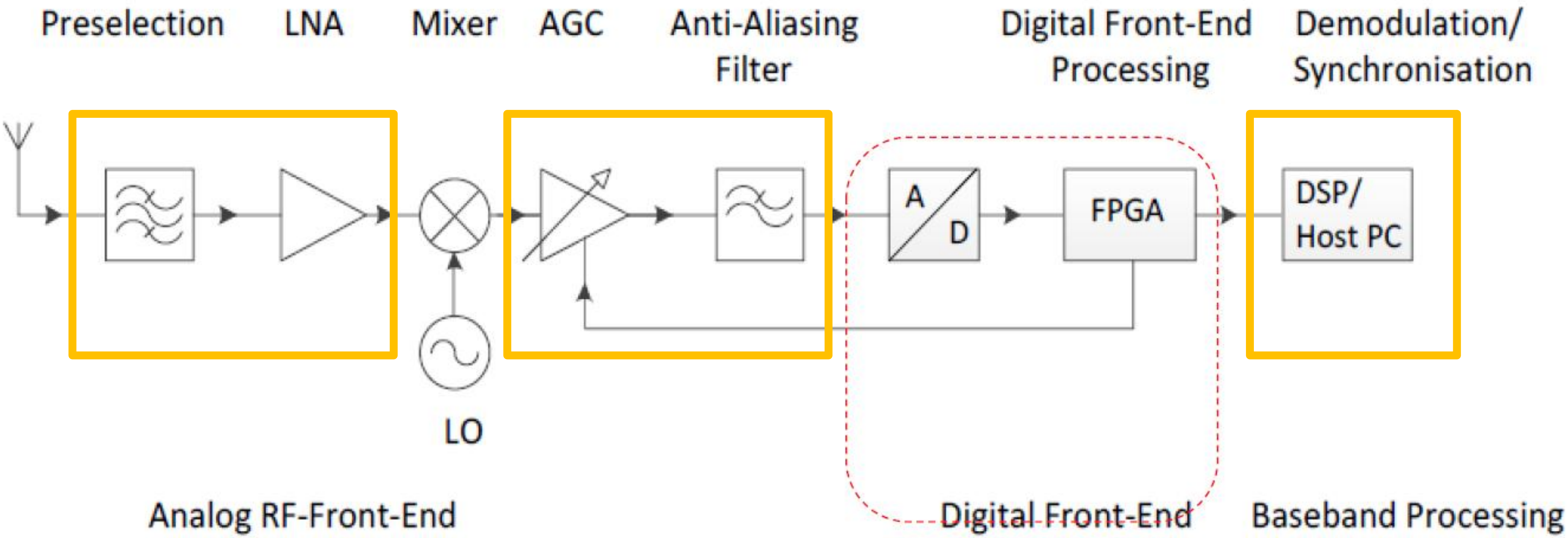
„The Art of Engineering“ is now to balance TX Effects with RX Effects which leads to an overall Data Sheet (Transceiver) with the best possible System Performance in Combination with lowest possible Costs for the Radio Architecture

THE WAY TO A GOOD SDR ARCHITECTURE

IT IS ALSO THE WAY INTO A GOOD PROJECT BECAUSE THE TECHNICAL SOLUTION IS KEY

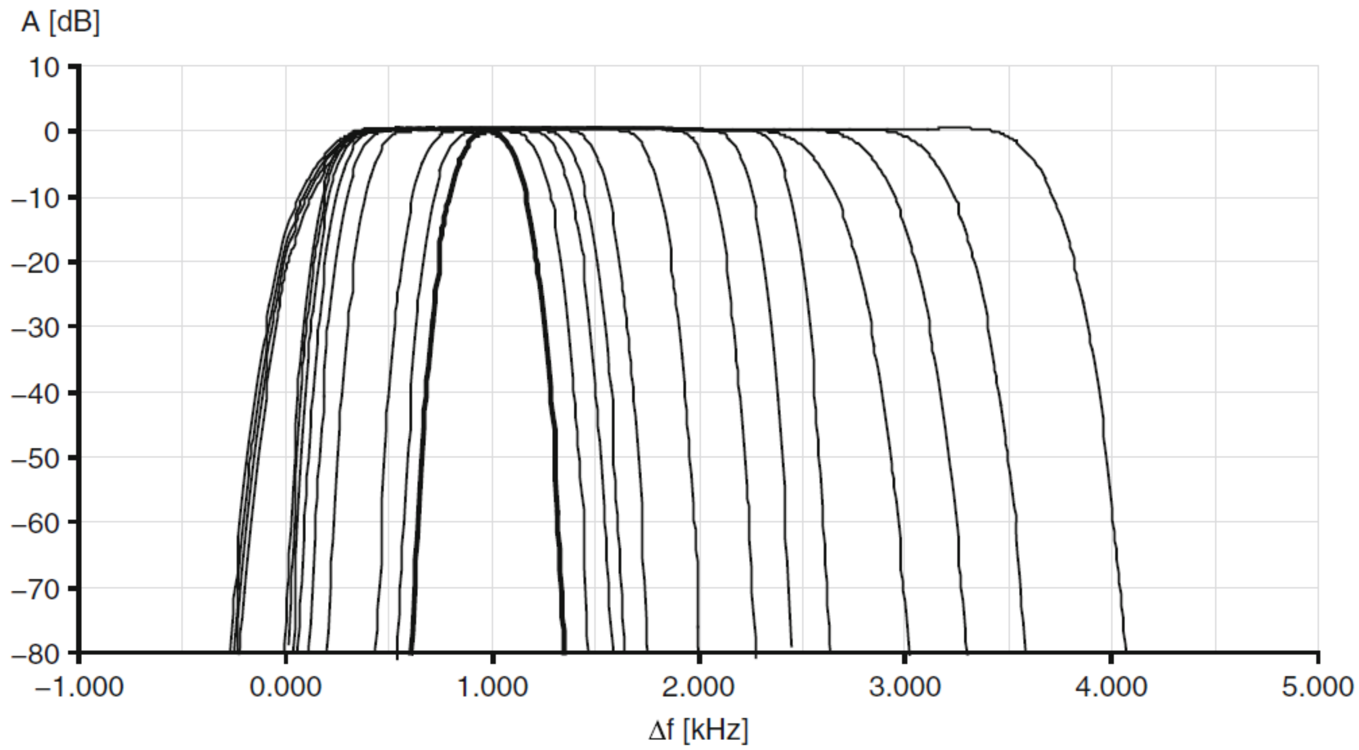
- A good SDR design is based on a combination of theoretical scientific knowledge with operational and practical experience.
  - The operational and practical experience says “what we need” and the theoretical scientific knowledge provides “how this can be achieved” → or
  - The theoretical scientific knowledge says “this is possible” and operational and practical experience says “what we need” or “what makes sense”
- The architecture plus some core details must be defined and realized by the most experienced people
  - These are e.g. analogue architecture, SW architecture… DSP + implementation aspects
  - Do not forget the usability e.g. user interface for easy operation ….
  - These people must also have a deep understanding of the operational context and Use Cases
- Field tests which are normally done quite late within a development project should just prove that we were right, they should not provide any surprises.
- Each SDR design must be operated in real “operational” scenarios before it is allowed to be delivered or even showed to any customer

A QUITE OFTEN USED BASIC ARCHITECTURE: SUPERHET



- ► **We will now pass some very important pieces of an SDR Receiver Architecture**
- ► **Filters, Noise Blanker, AGC, Frontend, …..**

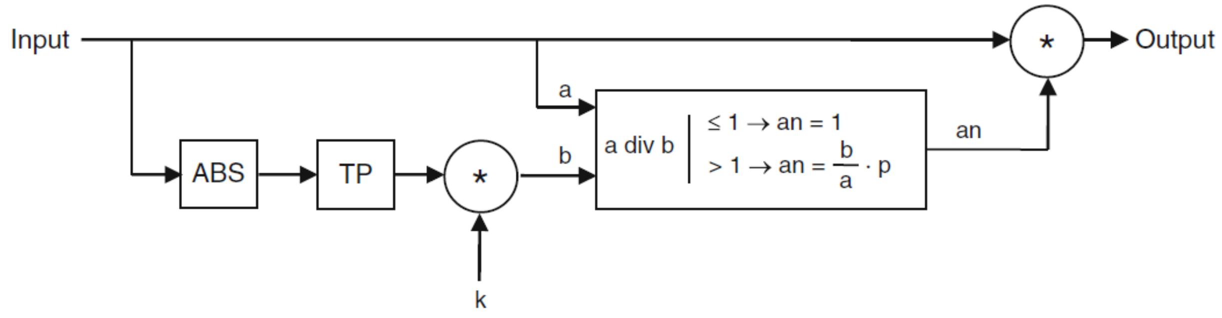
FILTERS: FREQUENCY RESPONSE FOR BEST “SOUND”
SSB VOICE IN HF COMMUNICATIONS RADIO → SDSR HF?

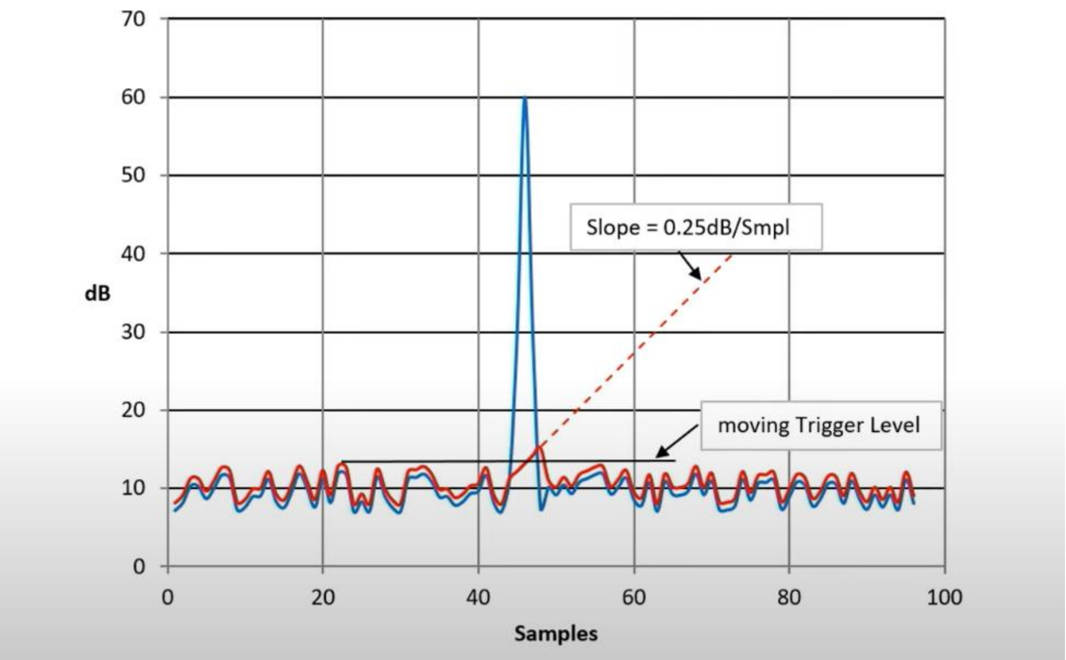


B (Hz)	fu (Hz)	fo (Hz)	Shape factor	Group delay (ms)
300	850	1150	2.29	20
500	750	1250	1.78	20
700	650	1350	1.55	20
1000	420	1420	1.38	20
1200	330	1530	1.32	20
1500	280	1780	1.26	20
1800	240	2040	1.21	20
2000	220	2220	1.19	20
2200	210	2410	1.18	20
2400	190	2590	1.32	12
2700	170	2870	1.29	12
3000	160	3160	1.26	12
3500	140	3640	1.22	12

► **Do not even think about a “rectangular” frequency response, sorry.**

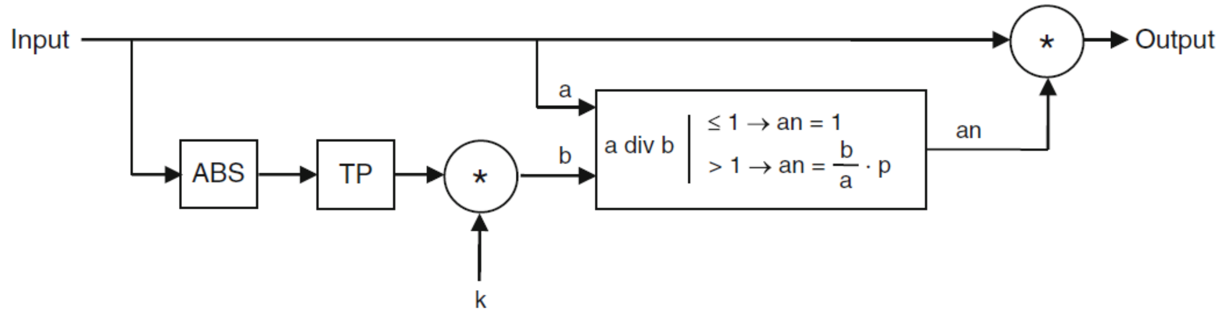
NOISE BLANKER FOR HF RADIOS



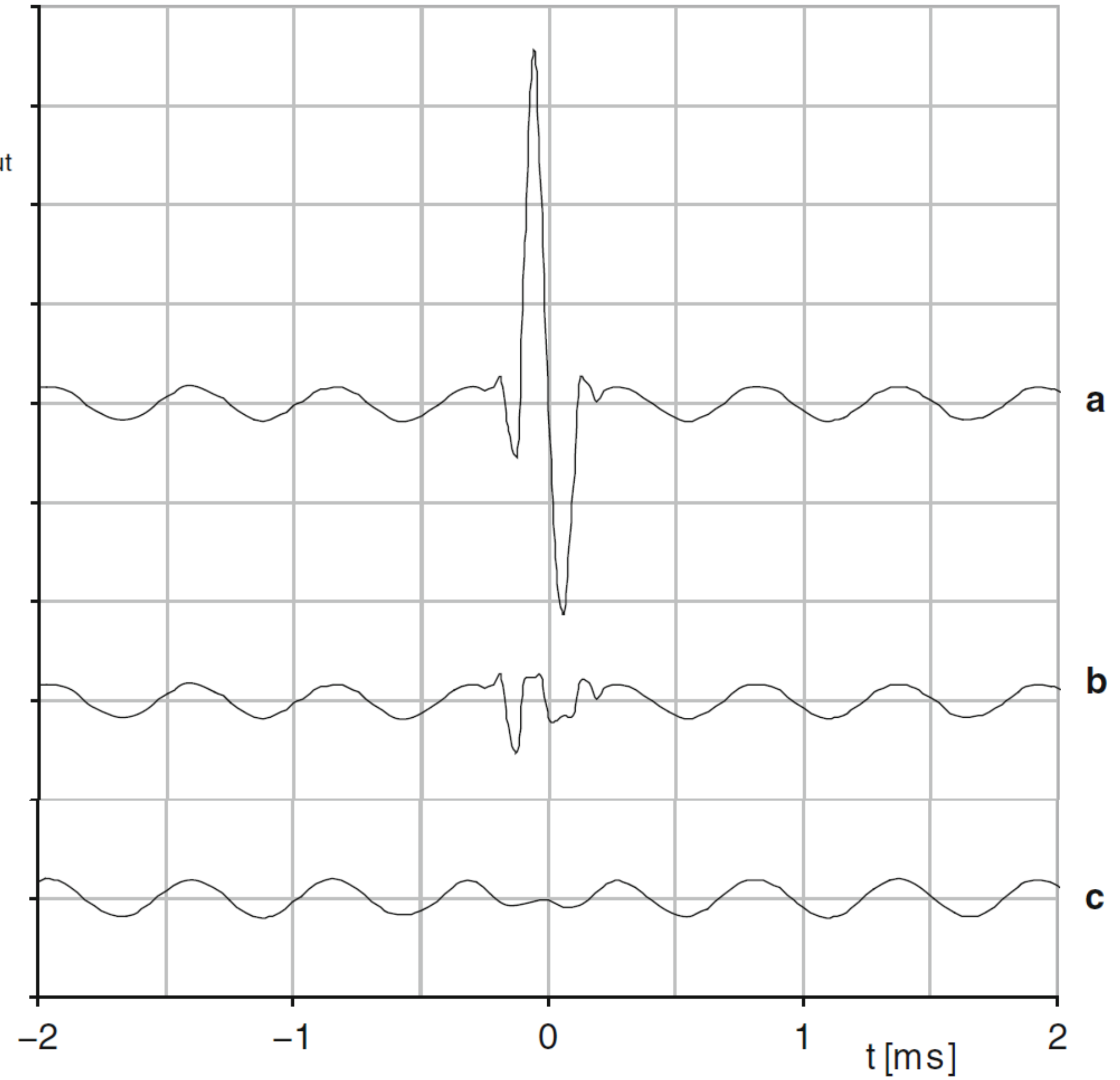


- ► The noise blanker used in this design was specially developed to suppress impulse noise and rampant amplitude changes
- ► This algorithm is effective to chancel sharp noise impulses. The factor k is setting the headroom about the filtered mean input value until the shaping is effective.
- ► When a > b then the input signal is scaled down to the level of b and is subsequently increased by the factor p for each sample.
- ► Therefore p is increasing from 1 with a delta of 0.5 dB per sample.
- ► Thus, a steep amplitude rising will be shaped with a ramp of 0.5 dB per sample, or 16 dB per millisecond. We have to consider, that this process is simply a gain variation and therefore linear and free from harmonic distortion.

NOISE BLANKER FOR HF RADIOS

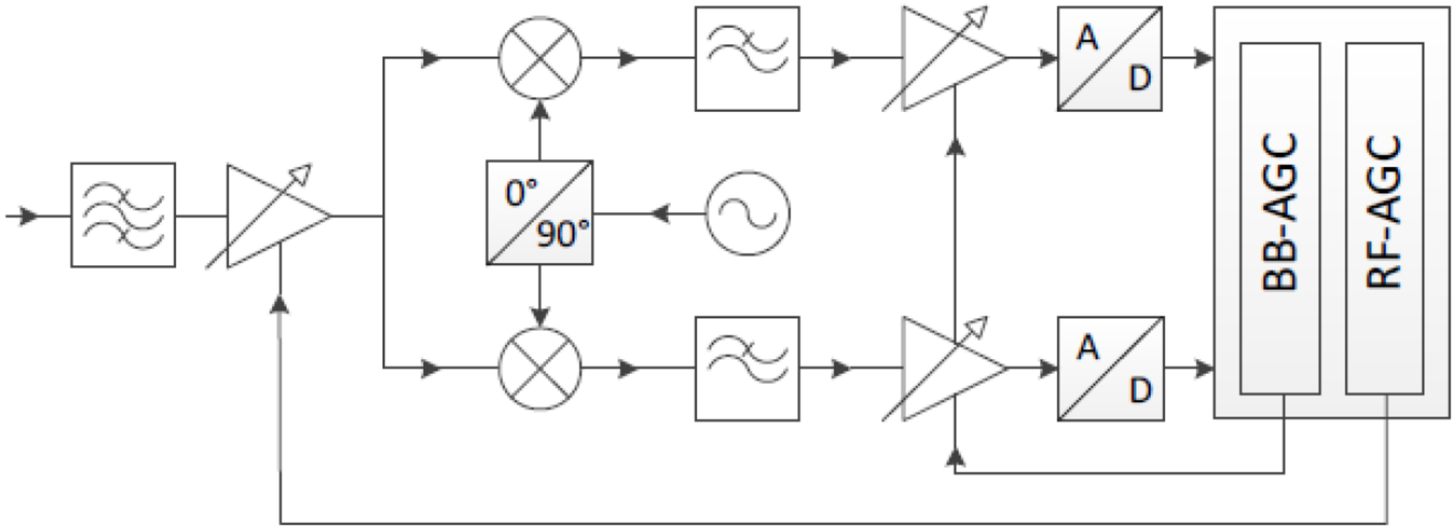


- Capability of the noise blanker (NB);
  - a at the input of the noise blanker
  - b noise blanker output
  - c smoothed audio output



AGC – AUTOMATIC GAIN CONTROL FOR SDR

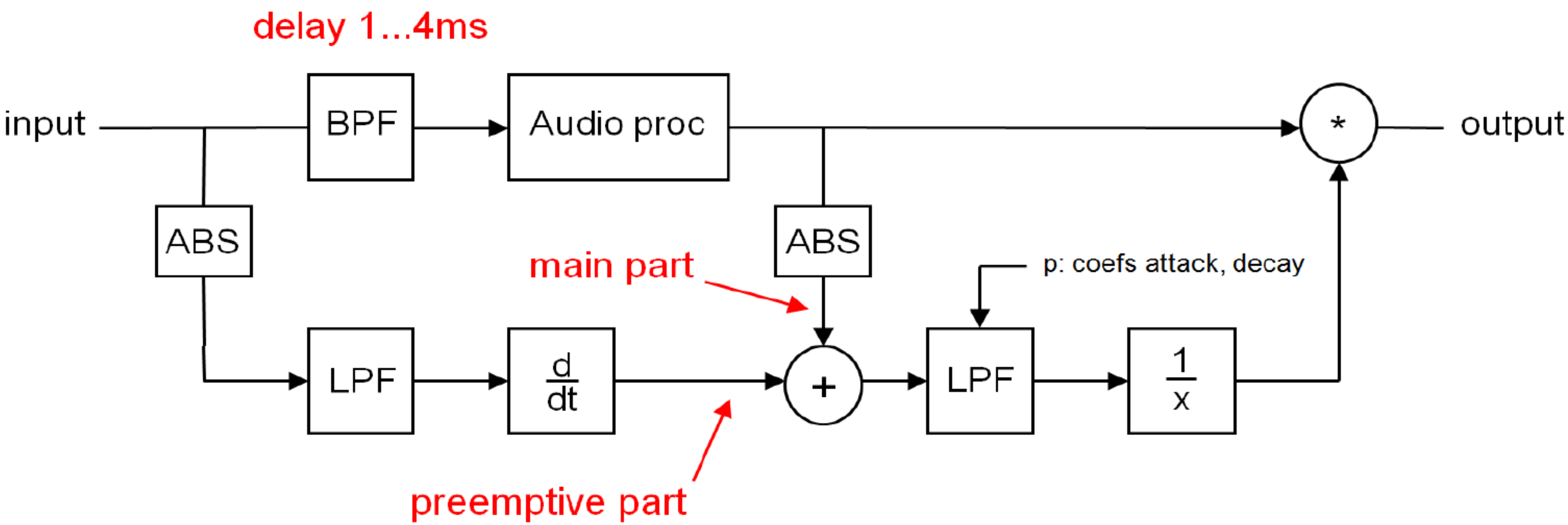
- A powerful AGC is one of the most important capabilities of an SDR architecture
- A good AGC design itself is a great piece of SDR science



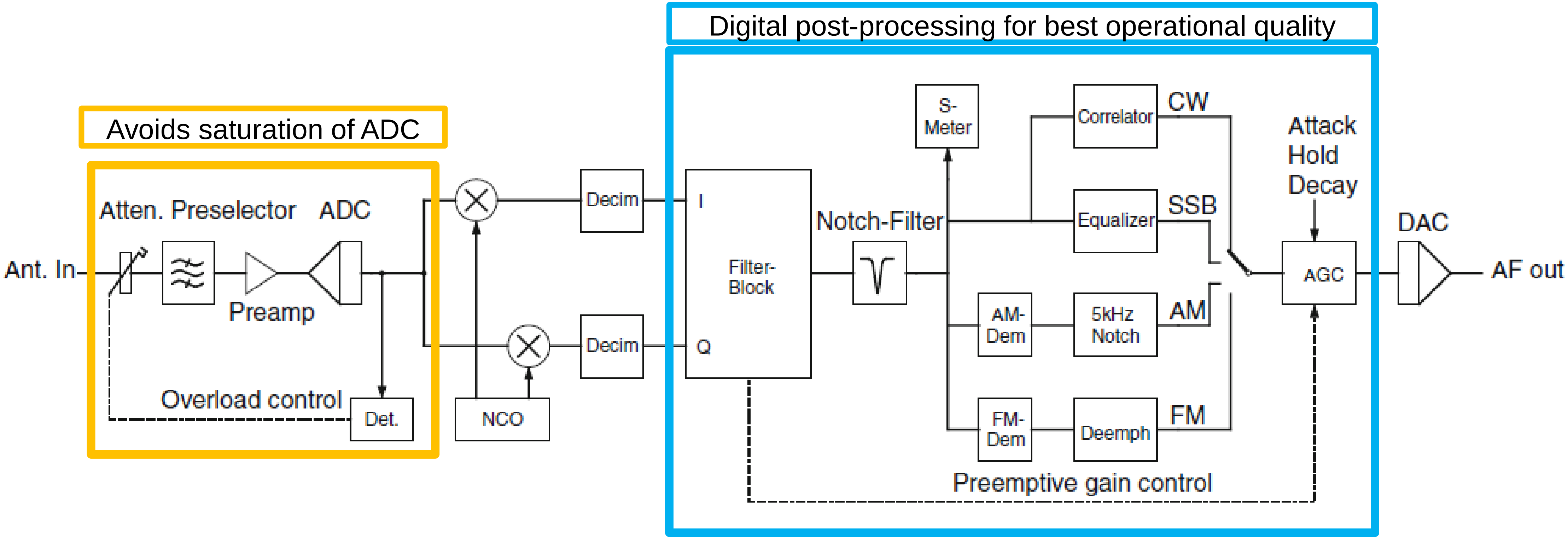
- The broadband AGC serves to protect the AD converter from overvoltages. The RF-AGC can be used to set the receiver sensitivity just below the external noise.
- The digital processing part is free from distortions, therefore the final AGC can be placed near the analog output.

AGC – AUTOMATIC GAIN CONTROL FOR SDR

- The main AGC control is realized near the of the signal processing chain as a feed forward control.
- This allows a perfect compensation of RF level variations between the antenna and the “ear of the user”-
- It is art to make the user feel comfortable sitting in front of a high end HF receiver.

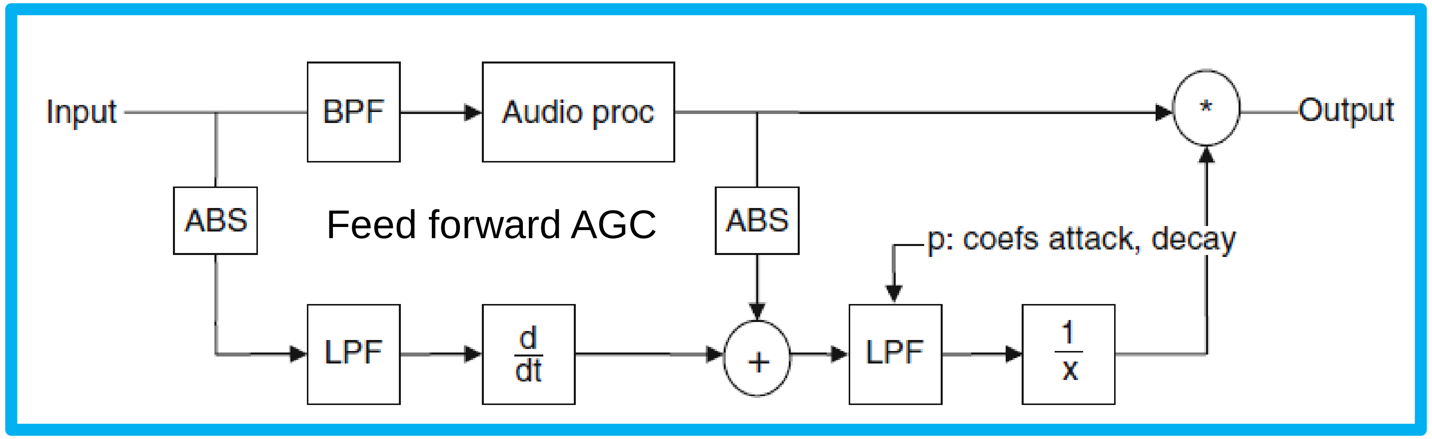


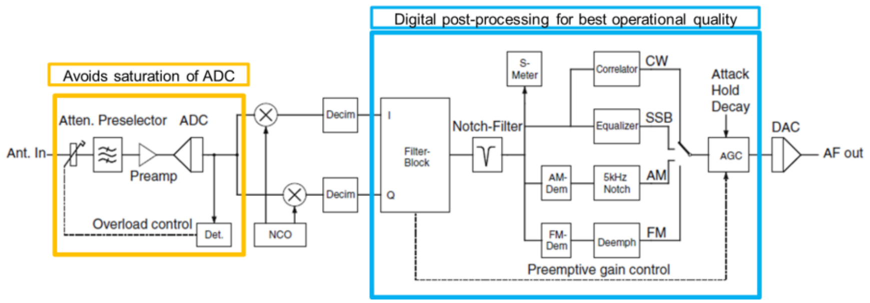
AGC – AUTOMATIC GAIN CONTROL FOR HF RADIOS
EXAMPLE TAKEN FROM ADT-200A – HANS ZAHND



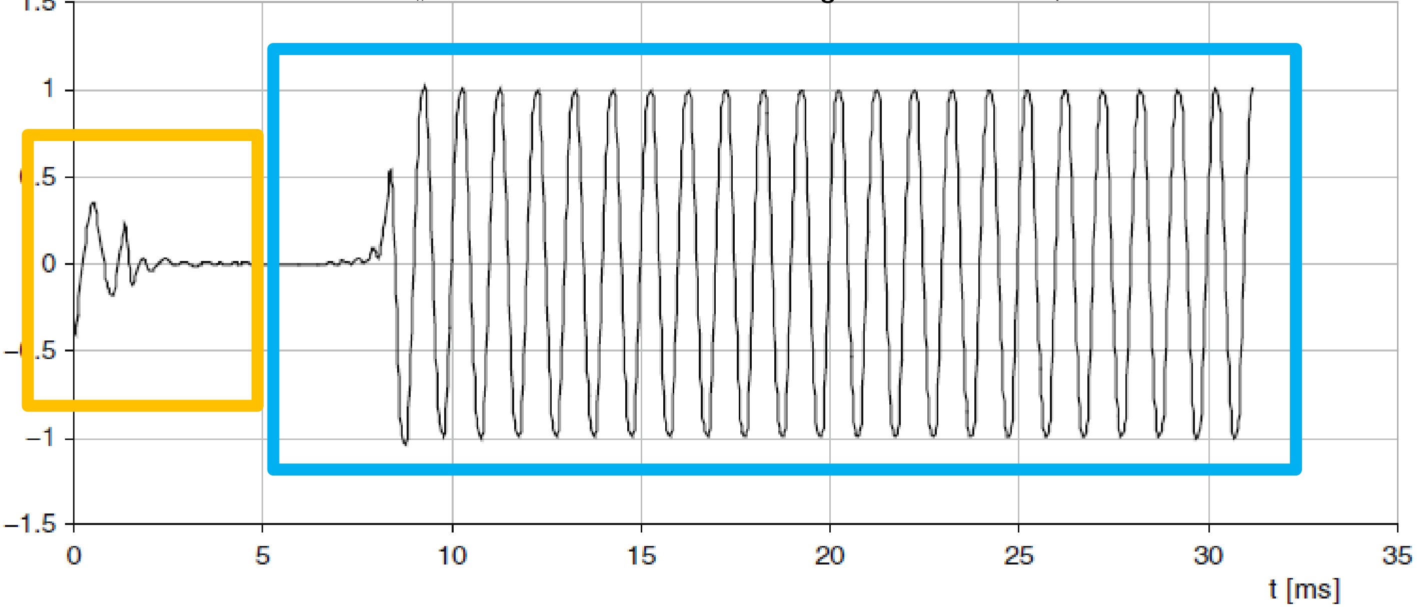
► This is a simplified block diagram of a direct sampling HF Receiver

AGC – AUTOMATIC GAIN CONTROL FOR HF RADIOS





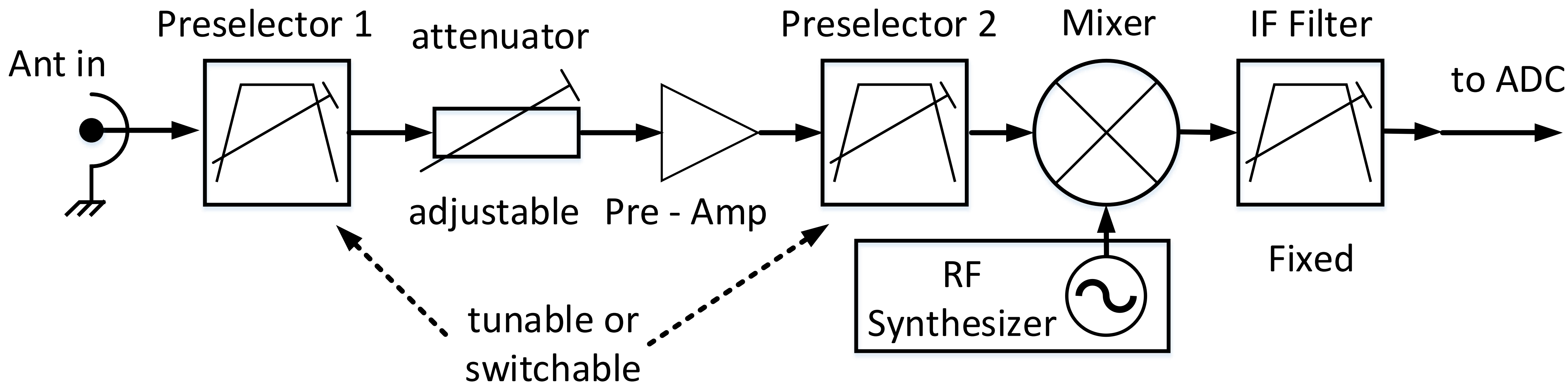
Rise of RF from „Noise“ at -120 dBm to full signal at -10 dBm , SSB Voice



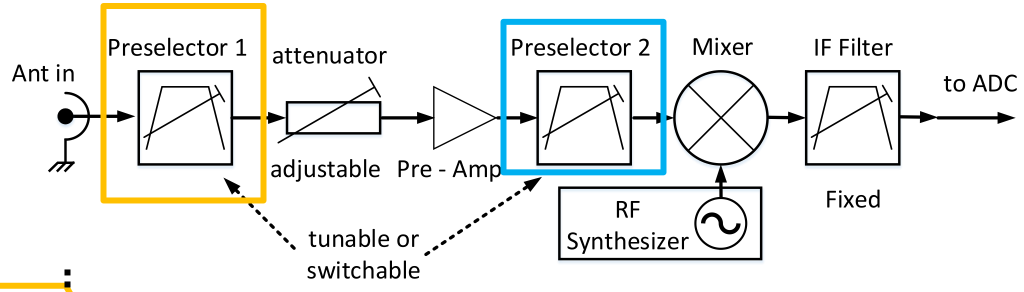
SSB Voice

Output Signal

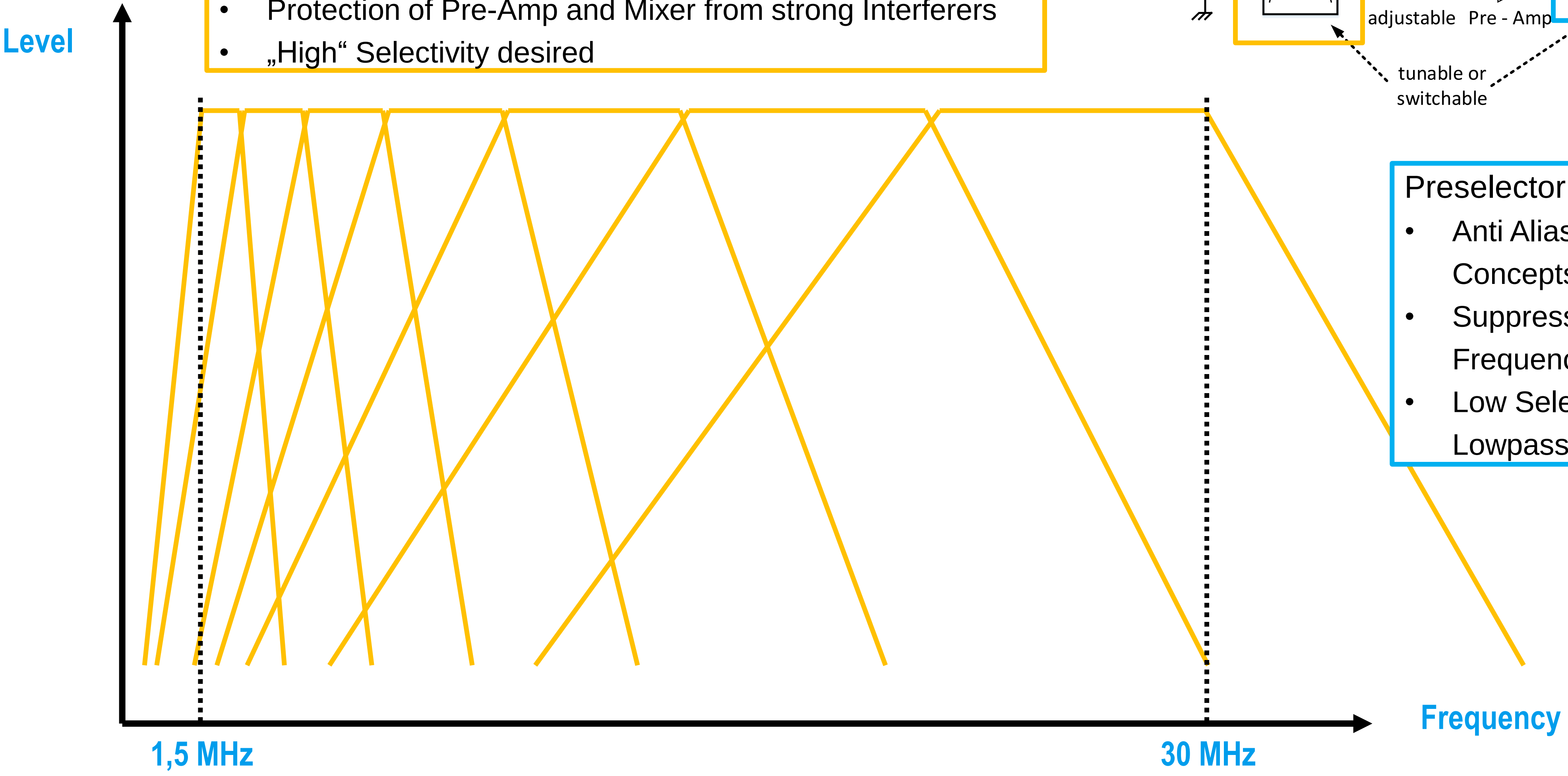
FRONTEND OF AN SDR → PRESELECTOR – LNA – MIXER
SUPERHET



FRONTEND OF AN HF SDR →PRESELECTOR – LNA – MIXER
HF - PRESELECTOR



Preselector 1 is for:
- Protection of Pre-Amp and Mixer from strong Interferers
- „High“ Selectivity desired

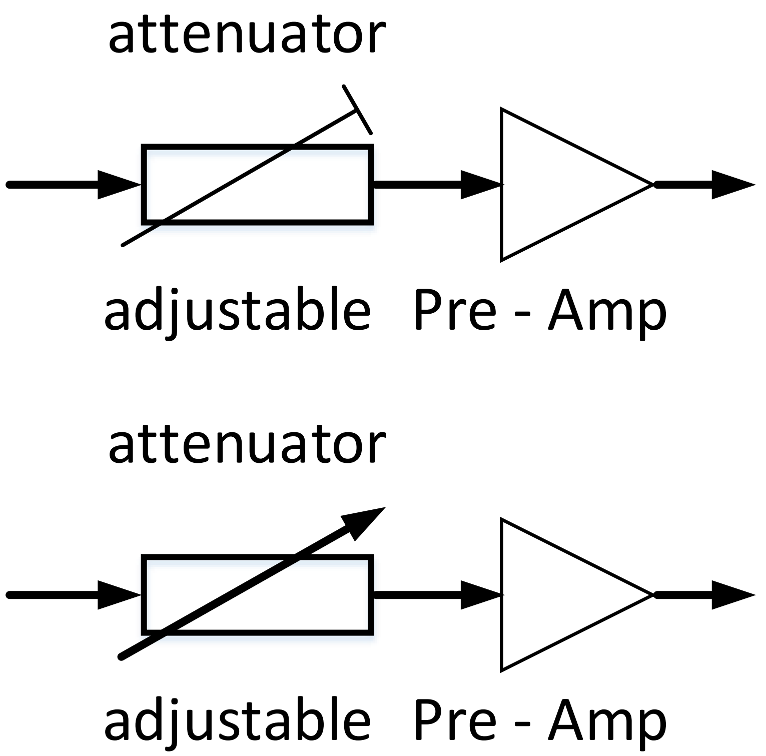


Preselector 2 is for:
- Anti Aliasing Filter in direct sampling Concepts
- Suppression of „LNA Noise“ on Image Frequency in Superhet Concepts
- Low Selectivity sufficient e.g. Lowpass, Notch etc.

FRONTEND OF AN SDR – PRESELECTOR – LNA – MIXER
PRE – AMPLIFIER → A VERY CRITICAL COMPONENT

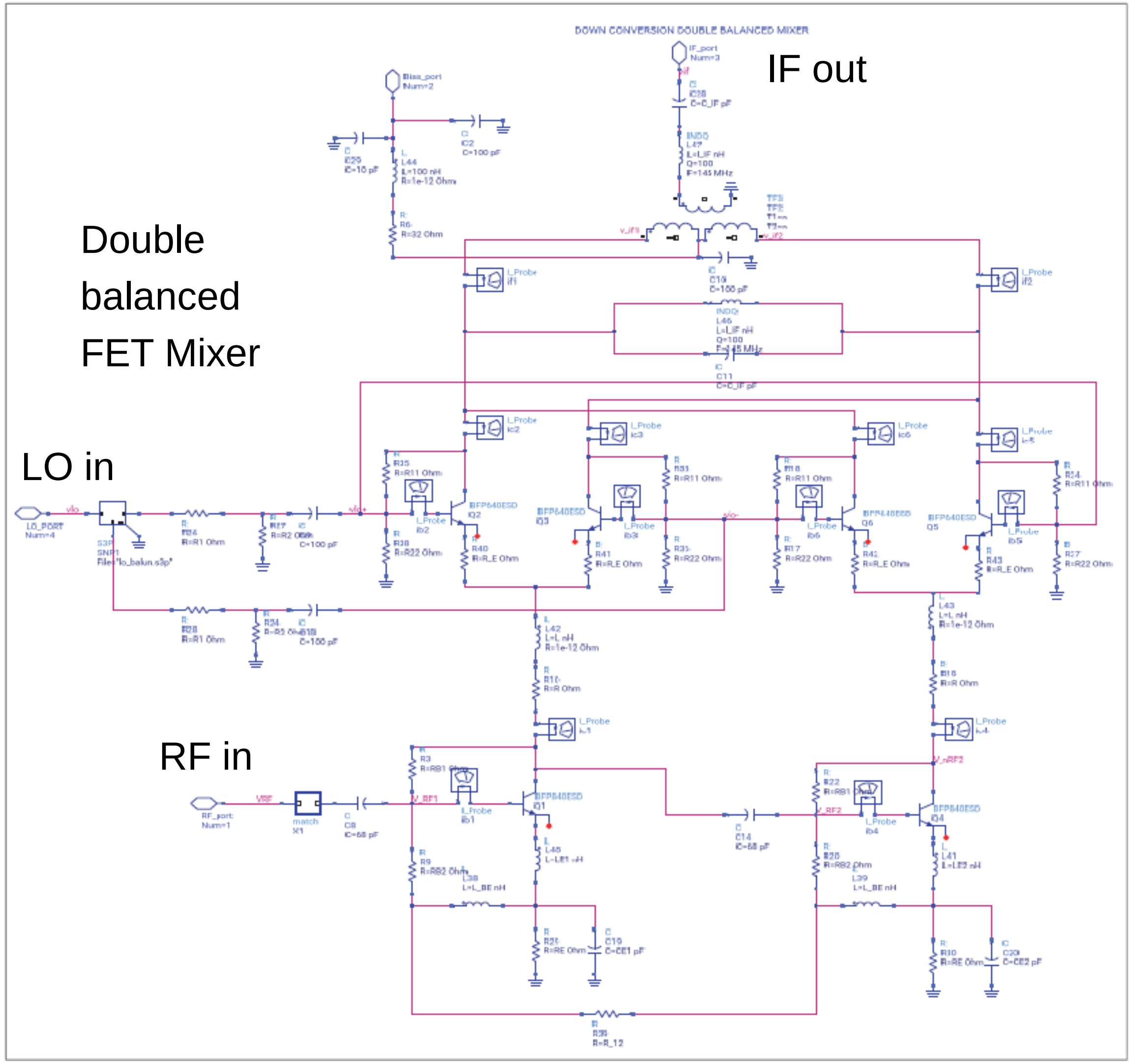
Pre – Amplifier and Attenuator are belonging closely together

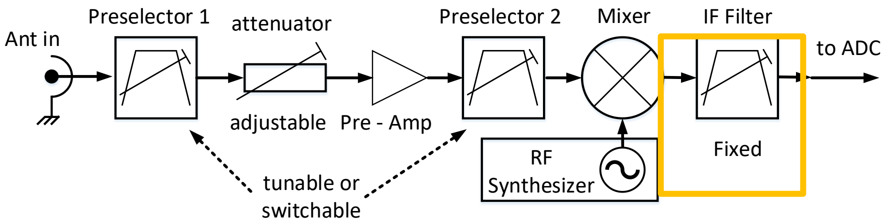
- Switchable attenuators are available with higher power capability compared to variable Attenuators BUT
- Variable Attenuators can be changed without causing BER in digital waveforms
- High Power Capability versus Power Consumption versus Noise figure, this is the challenge
- Moderate Gain (10 - 15 dB) desired but quite often only achived by using feedback circuits.
- P1dB beyond 20 dBm required in critical Cosite Environments



FRONTEND OF AN HF SDR →PRESELECTOR – LNA – MIXER

MIXER FOR LOW POWER UHF RECEIVERS





MATHEMATICAL ANALYSIS, DESIGN, AND VALIDATION OF A HIGH DYNAMIC RANGE, LOW NOISE DIFFERENTIAL MIXER USING SiGe MICROWAVE TRANSISTORS

A doctoral thesis submitted to the **faculty 1 - MINT - Mathematik, Informatik, Physik, Elektro- und Informationstechnik** of the Brandenburg University of Technology Cottbus-Senftenberg for the academic degree of **"Dr.Ing"**

By

TRUSHA KARED

First and foremost, I would like to extend my deepest gratitude to my supervisor, **Prof. Dr. Ing. -habil. Dr. h. c. mult. Ulrich L. Rohde** for his unwavering support, guidance, and encouragement. His insightful feedback and expertise were crucial in shaping the direction of my research, and I am deeply grateful for his mentorship.

I am truly thankful to **Prof. Dr. Ing Matthias Rudolph** for his support and for providing thorough and effective insights during this very advanced microwave transistor-related work.

I am truly thankful to **Prof. Dr. Ignaz Eisele**, Professor der Universität der Bundeswehr München, who gave me important insight into SiGe semiconductor physics.

UNIQUE FEATURES

MULTIPLE INPUT CHANNELS

- First signal analyzer with multiple input channels
  - Phase coherent measurements on multiple channels

NEW MULTI-PATH INTERNAL ARCHITECTURE

- Cross correlation (high dynamic range for noise, phase noise and EVM measurements)
- Extended spurious free dynamic range

NEW SW ARCHITECTURE

- Easy setup of multiple channel measurements
- Intuitive activation of cross correlation analysis
- Linux (YOCTO-377)

FREQUENCY RANGE: 44 GHz, ... 70 GHz, 130 GHz

- Unique instrument covering the frequency range up to 130 GHz as one box solution with pre-selection

ANALYSIS BANDWIDTH: 8 GHz

- Widest bandwidth on the market

FILTER BANKS FOR PRE-SELECTION IN THE MICROWAVE RANGE

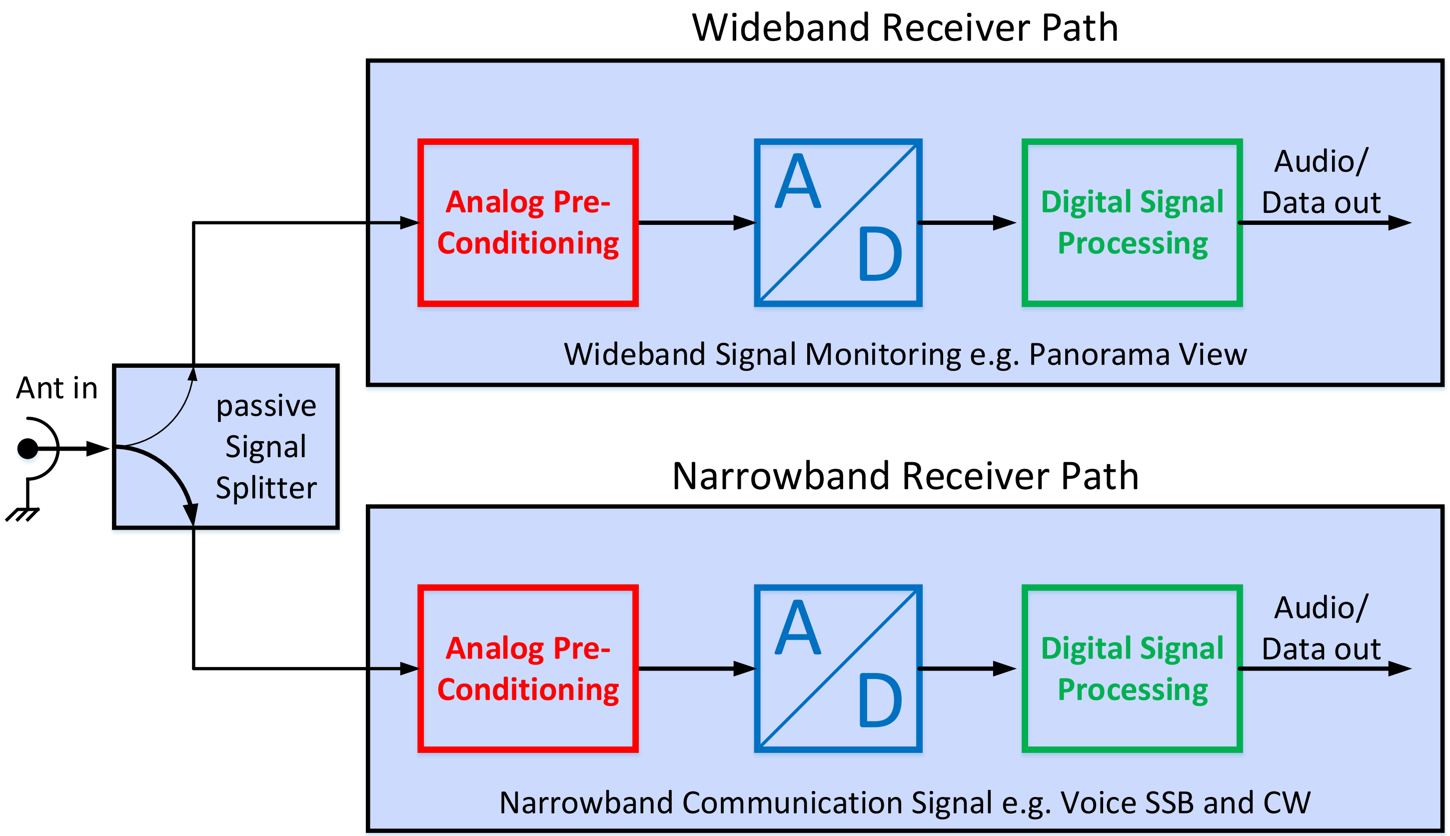
- 5 times faster sweep
- Higher level accuracy
- Optional YIG-filter for pre-selection

The FSW is a masterpiece of RF engineering

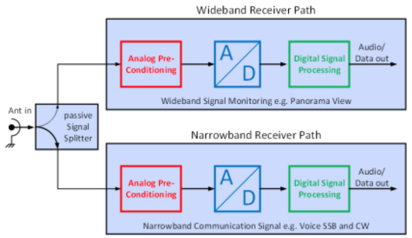
Its incredible Blockdiagram would fill a separate presentation

LET´S BUILD NOW A “PERFECT” HF RECEIVER

- We want to monitor a wideband spectrum e.g. waterfall diagram and a narrowband signal at the same time.
- We combine therefore two different receiver paths.
- The wideband path is for sure a direct sampling concept today.
- The narrowband path maybe different.
- Even in cases where both are using the same block diagram they may use at least different settings e.g. for AGC and others.
- This configuration is standard in the meantime in many HAM equipment.
- An example for boths paths on the next slide

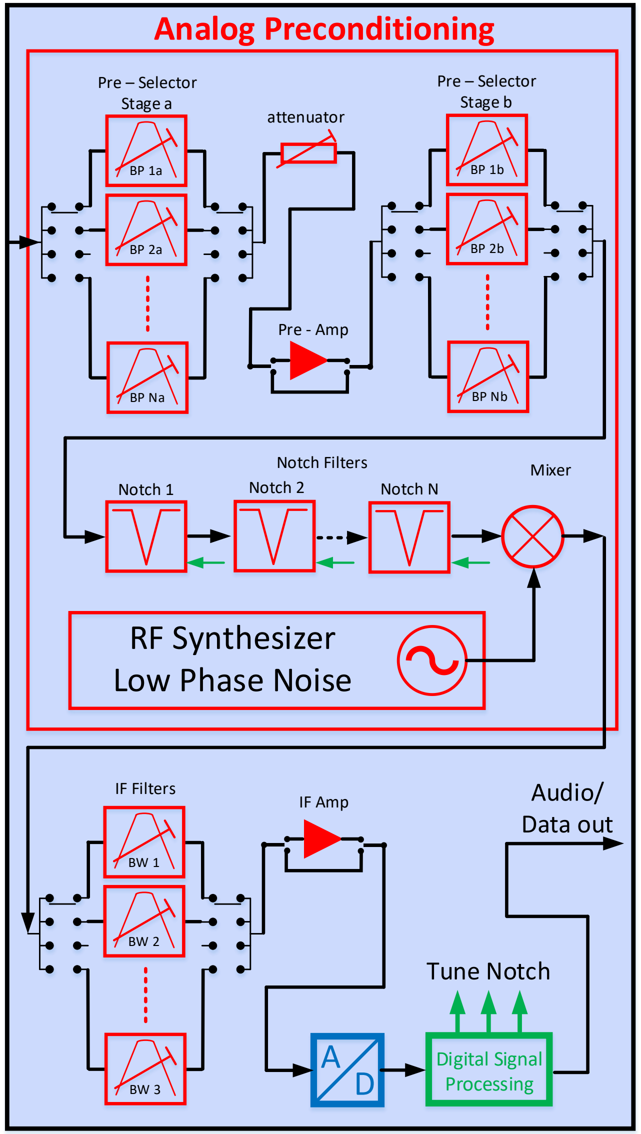


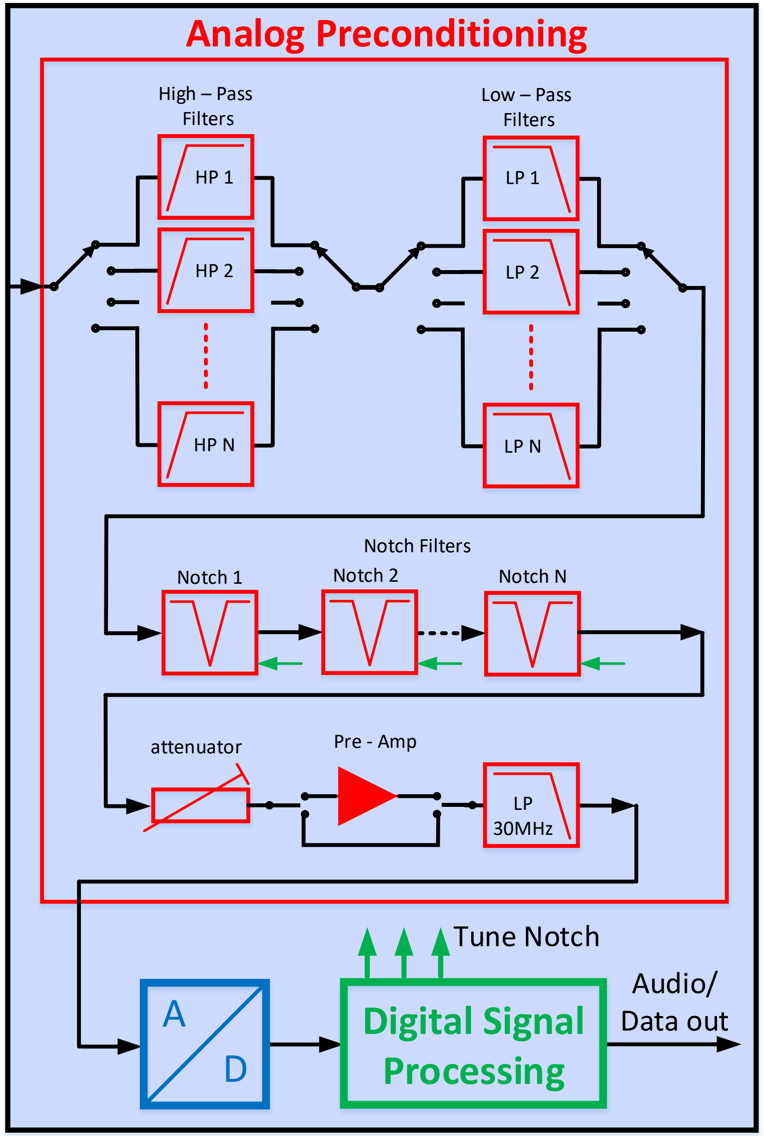
LET´S BUILD NOW A “PERFECT” HF RECEIVER



Example for

IF Sampling





Example for

Direct Sampling

LET´S BUILD NOW A “PERFECT” HF RECEIVER

WHAT WE CAN EXPECT FROM A GOOD DATA SHEET

► Basic Data without Interferers present:

- Tuning range: 10 kHz up to 30 MHz
- Max. Noise figure of RX without Interferer with Pre – Amp on:
  - Path 1 Wideband: 10 dB
  - Path 2 Narrowband 15 dB
- Max. allowed Difference between Interferer and wanted Signal:
  - Path 1 Wideband: (Direct sampling)
    - A1A (200Hz): 95 dB
    - J3E (3000Hz): 95 dB
  - Path 2 Narrowband: (IF sampling)
    - A1A (200Hz): 150 dB
    - J3E (3000Hz): 140 dB
- Sensitivity of RX without Interferer (pre Amp on)
  - Path 1 Wideband:
    - A1A (200 Hz): -135 dBm or 0,04 µV
    - J3E (3000 Hz): -123 dBm or 0,16 µV
  - Path 2 Narrowband:
    - A1A (200 Hz): -130 dBm or 0,07 µV
    - J3E (3000 Hz): -118 dBm or 0,28 µV

► Enhanced Data with clean Interferers present:

- Sensitivity of RX with Interferer present
  - Use case 1 military: 1000 W with -180 dBc/Hz @ 10% and an antenna decoupling of 15 dB
  - Use case 2 amateur: 150 W with -180 dBc/Hz @ 10% and an antenna decoupling of 25 dB
  - Use case 3 amateur: 150 W with -150 dBc/Hz @ 100 kHz and an antenna decoupling of 25 dB
  - Path 1
    - Use case 1 (with pre - selector >55 dB@10%):
      - A1A (200 Hz): -106 dBm or 1,12 µV
      - J3E (3000 Hz): -94 dBm or 4,46 µV
    - Use case 1 (without pre - selector):
      - Any mode – 50 dBm or 710 µV
    - Use case 2 (with pre - selector >55 dB@10%):
      - A1A (200 Hz): -124 dBm or 0,14 µV
      - J3E (3000 Hz): -112 dBm or 0,56 µV
    - Use case 2 and 3(without pre - selector):
      - Any mode – 68 dBm or 89 µV
  - Path 2 Narrowband:
    - Use case 1:
      - A1A (200 Hz): -106 dBm or 1,12 µV
      - J3E (3000 Hz): -94 dBm or 4,46 µV
    - Use case 2:
      - A1A (200 Hz): -123 dBm or 0,16 µV
      - J3E (3000 Hz): -111 dBm or 0,63 µV
    - Use case 3:
      - A1A (200 Hz): --94 dBm or 4,46 µV
      - J3E (3000 Hz): -82 dBm or 18 µV

SOME REFERENCES

- MATHEMATICAL ANALYSIS, DESIGN, AND VALIDATION OF A HIGH DYNAMIC RANGE, LOW NOISE DIFFERENTIAL MIXER USING SiGe MICROWAVE TRANSISTORS - A doctoral thesis submitted to the faculty 1 - MINT - Mathematik, Informatik, Physik, Elektro- und Informationstechnik of the Brandenburg University of Technology Cottbus-Senftenberg for the academic degree of “Dr. Ing” by Trusha Kared
- Hans L. Hartnagel, Rüdiger Quay, Ulrich L. Rohde, Mathias Rudolph, *Fundamentals of RF and Microwave Techniques and Technologies*, Springer
- Ulrich L. Rohde, Jerry C. Whitaker and Hans Zahnd, *Communications Receivers: Principles and Design*, McGraw Hill, Fourth Edition, 2017.
- Paul Denisowski (KO4LZ), “*The Rebirth of HF*” White Paper Rohde & Schwarz North America.
- SDRA – Software Defined Radio Academy 2025, 25 Years of SDR, how far has it come? Hans Zahnd HB9CBU, https://www.youtube.com/watch?v=i47TnthjL0Q
- Next Generation Networks: Software Defined Radio - Emerging Trends , IEEE MTT-S Hyderabad Chapter , Sponsors Speaker Bureau Talk, Sir J C Bose Memorial Lecture Event, December 02, 2016 by Prof. Dr. Ing. habil Ulrich L. Rohde, Brandenburg University of Technology, Cottbus, Germany, Bavarian Academy of Science, Munich, Germany, Indian Institute of Technology, Delhi, India, Oradea University, Romania
- Direct RF Technologies, Transform Aerospace and Defense Systems, Rodger Hosking, Mercury Systems / Signal Technologies, IEEE New Jersey Chapter, 39th Annual Symposium & Mini-Show, October 9, 2025
- For further reference feel free to search also https://orcid.org/0009-0009-2271-4438 which an great overview of publications from Prof. Ulrich L. Rohde

PART 4

1. SDR implementation aspects

ROHDE&SCHWARZ

Make ideas real

A CHECKLIST FOR WAVEFORM ARCHITECTS + PRODUCT
GOAL OF THIS CHECKLIST: GET A BETTER UNDERSTANDING ABOUT THE USE CASES

- If we intend to define a radio waveform it is already important to know whether a battery powered device will be connected
  - SWaP-C is essential and must be on the table as the very first questions → implementation aspects
  - A low SWaP device is normally NOT a miniaturized big device, it can be something completely different, but beeing interoperable.
- Are we talking about waveforms for civilian or military use?
  - Civilian waveforms (e.g. for cellphones) want to be connected at anytime anywhere → very active in transmission
  - Military waveforms have to work in hostile environment e.g. „if you are detected you are shot down"
  - The most important mode for a military radio is „radio silence" which is struggling with „combat cloud connectivity" ideas
- Do we talk about static or highly dynamic platforms ? → e.g. Doppler for RF Frequency + data/clock rates of waveforms
- Radio Propagation
  - LOS or BLOS ? In free space or above water, terrain etc.
  - Minimum required ranges? → range has two implications: Delay (1ms for 300km) and attenuation
- Oszillators, frequency drift over time
- System Installation → SIMOP, COSITE
- Environmental Conditions

A CHECKLIST FOR ARCHITECTS OF EQUIPMENT + WAVEFORMS
OUR RECOMMENDATION TO HAVE A CHECKLIST

What may happen if such a checklist is not used? → an example:

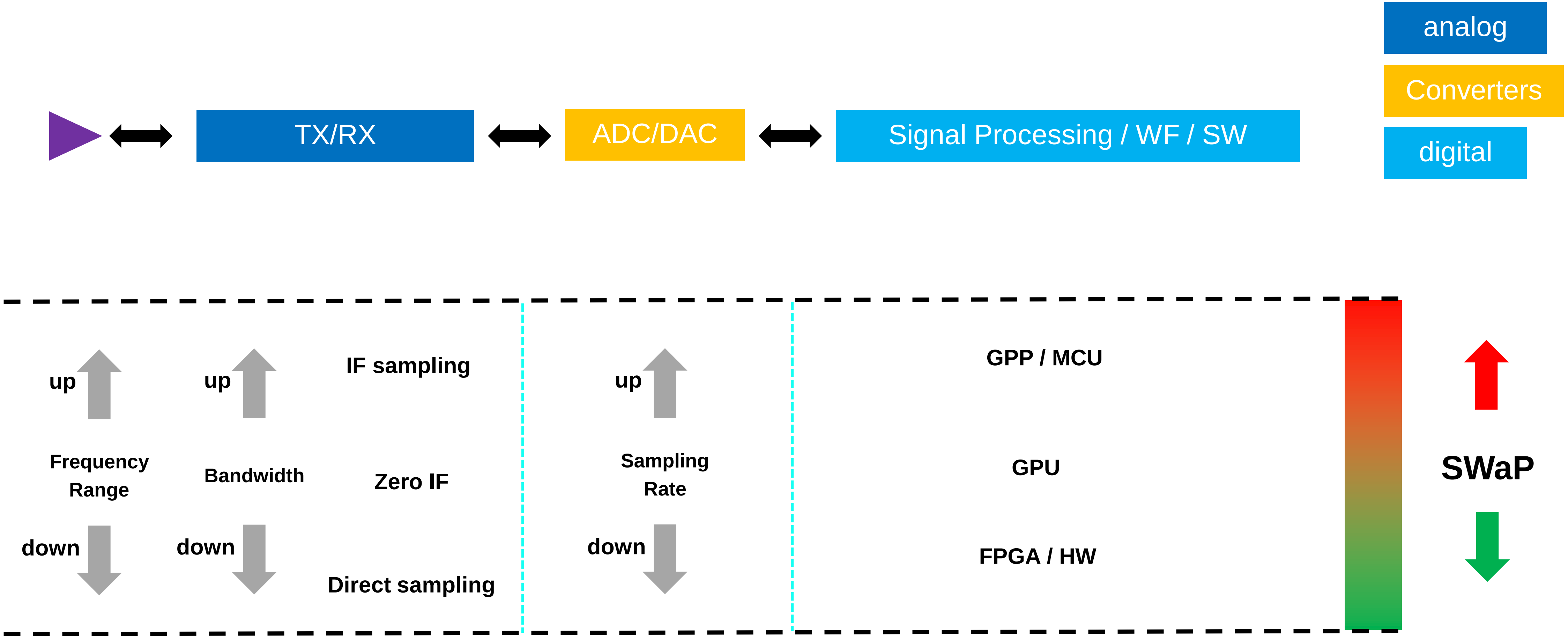
NASA ESA Lander Doppler Effect Problem with Cassini – Huygens Lander → a 3 Billion Dollar Problem!

- SDR Engineers (Alenia Spacio) have just not carefully analysed that during a descent of the Hyugens probe to the SATURN moon Titan a too high doppler profile (RF offset and clock offset) may occure.
- This was found when the spacecraft mission crew prepared for separation after years of flight.
- The mission was close to end in a desaster but it was rescued by changing the orbit for Cassini for the decent period.

The Cassini-Huygens mission was launched in 1997. Engineers last year identified a design flaw in the Huygens communications system. Without a change in flight plans, the Huygens receiver would be unable to compensate enough for the Doppler shift in radio frequency between the signal emitted by the probe and the one received by the orbiter. A Doppler shift happens when the distance between a transmitter and receiver is changing, and Cassini originally would have been rapidly approaching Titan during Huygens' descent. This would have resulted in the loss of important data from the probe during its trip through Titan's atmosphere.

More information about Cassini-Huygens is available online at http://www.jpl.nasa.gov/cassini/ and at http://sci.esa.int/huygens/.

SWaP ARE OFTEN ESSENTIAL AND NEED TO BE FIXED FIRST
→ SOME TYPICAL TRENDS



IMPLEMENTATION ASPECTS
USER NEEDS

- Use Case SDC (Software Defined Car):
  - „Gentlemen start your engine“
- Question:
  - What is the maximum time you are willing to accept between „pressing“ the Start/Stop button and „the car starts to move“?
  - 1 Second, 5 Seconds, 30 Seconds, more ? ….

- If we were the developer of our own car we could set any requirement which we see ok for us.
- If we develop products for our customers/users we should take care about their requriements as if these were our own → But why are we acting different here? → Boot time of radios

IMPLEMENTATION ASPECTS

- We are talking about **S**DRs → so **SW** is an essential part.
- But we see quite often that the SW acrhitecture is or was optimized for the „implementation process“ but not for what the SW shall do for the user

  → big code, big SWaP, big development teams, not flexible, long boot process and finally POOR performance

  → The definition of a SW architecture requires the „user mindset“ of SW people, sorry.

- The way how SW is implemented MUST NOT NEGATIVELY influence the usability of the product

- We must keep the users (our customers) in the focus

  → If the **S**W is **D**efined, it is a **R**adio so it must behave as a radio

  → **All** parts of an SDR architecure shall be dedicated to customer usability

PART 5

1. Some Conclusions
2. Q&A

ROHDE&SCHWARZ

Make ideas real

CONCLUSIONS - 1

- SW Defined Technology is omnipresent – but not only within the RF part of the products
- Direct Sampling, IF Sampling and Zero – IF concepts have their reason and will continue in their specific use cases.
  - IF sampling is normally more robust while direct sampling provides more bandwidth and detection speed.
  - For analogue waveforms e.g. ATC AM Voice a zero IF concept will lack of sufficient SNR under doppler conditions.
- An SDR RF architecture incorporates some very important details which require very high attention by the best engineers like AGC, Puls Blanker, Filter design, Squelch and others.
- A good SDR Architecture is nothing for beginners!
- Size, weight and power plus cost must be analyzed first before any bulding block or any other detail of an SDR architecture is developed.
- Finally the product must solve our cutomer´s problems

CONCLUSIONS - 2

- Think about your users.
- The right technical concepts are the basis for our success
- All eningeers must dedicate their concepts and their disciplines to their users needs.
- Our founders showed us how the combination of technical expertise and a deep understanding of user needs lead to world class products with

- Our founding fathers Dr. Schwarz (left) and Dr. Rohde (right) showing some of the very first measurement equipment.

- Many Thanks for this Inspiration. It is an honor for us to continue this success story.

QUESTIONS PLEASE

Many thanks for your attention