Connecting technical, business and regulatory leaders ~ Defining the future of radio communications

11-13 March 2014 ~ Schaumburg, Illinois

Microwave Receiver and Design Principles

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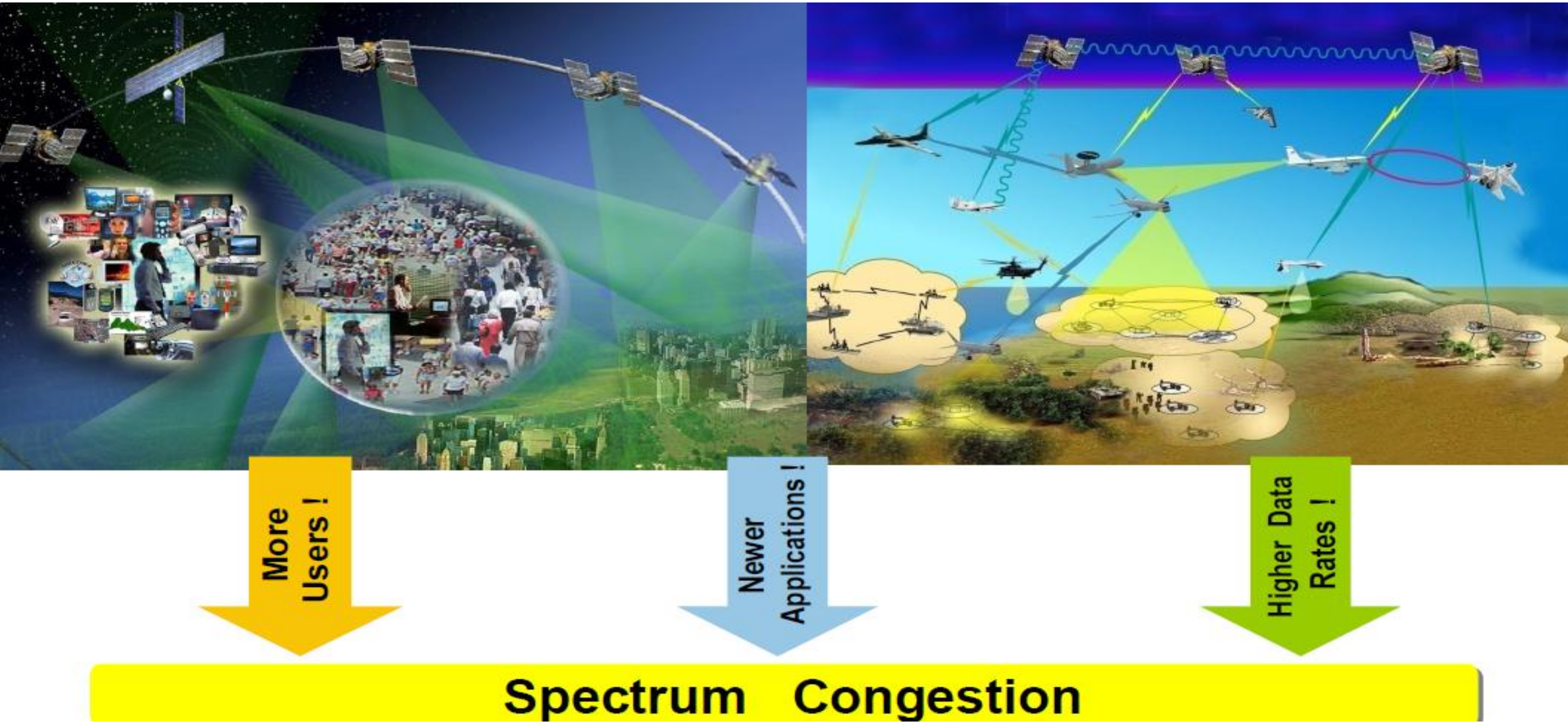
High Performance Receiver Needed Everywhere !

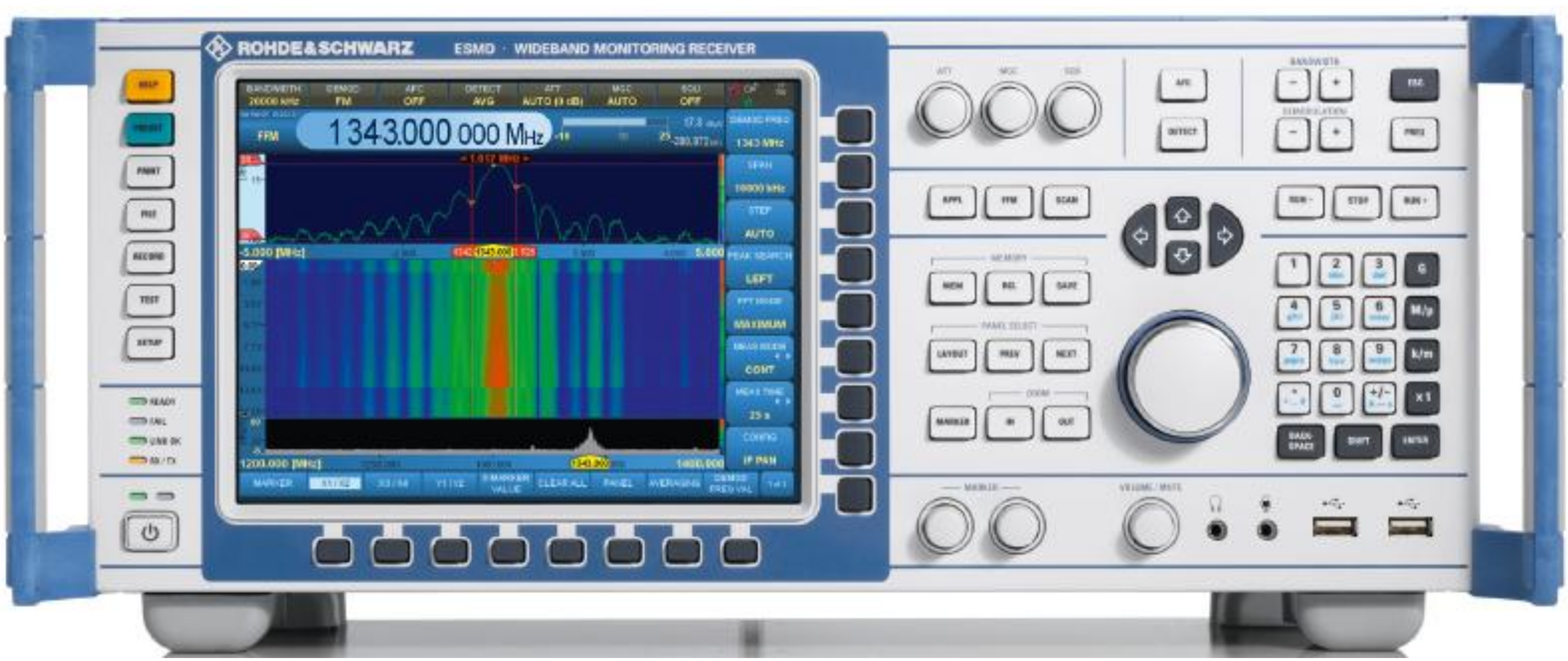


Looking for ?

Microwave High Performance Monitoring Receiver Solution 20MHz-60GHz ?

Widebnad Monitoring Receiver

R&S ESMD Wide Band Monitoring Receiver



High Dynamic Range !!!

Monitoring Receivers

High Dynmaic Range Microwave Monitoring Receivers

- Searching for faults in professional radio networks
- Comprehensive spectrum analysis
- Monitoring of user-specific radio services
- Monitoring on behalf of regulating authorities
- Handoff receivers, i.e. **parallel demodulation** of narrowband signals and simultaneous broadband spectrum scanning=High Dynamic Range
- Critical Parameters: Noise Figure, IP2, IP3, and instantaneous dynamic range

Best solution: ⇨ Software Defined Radio

Software Defined Radio

Software Defined Radio

- Want to make all parameters digitally tunable
  - What Parameters?
    - **RX/TX Frequency**
    - **Bandwidth**
    - **Impedance Match**

Software Defined Radio

- Definition:

  A Software Defined Radio (SDR) is a communicaton system, where the major part of signal processing components, typically realized in hardware are instead replaced by digital algorithms, written in software“ (FPGA).

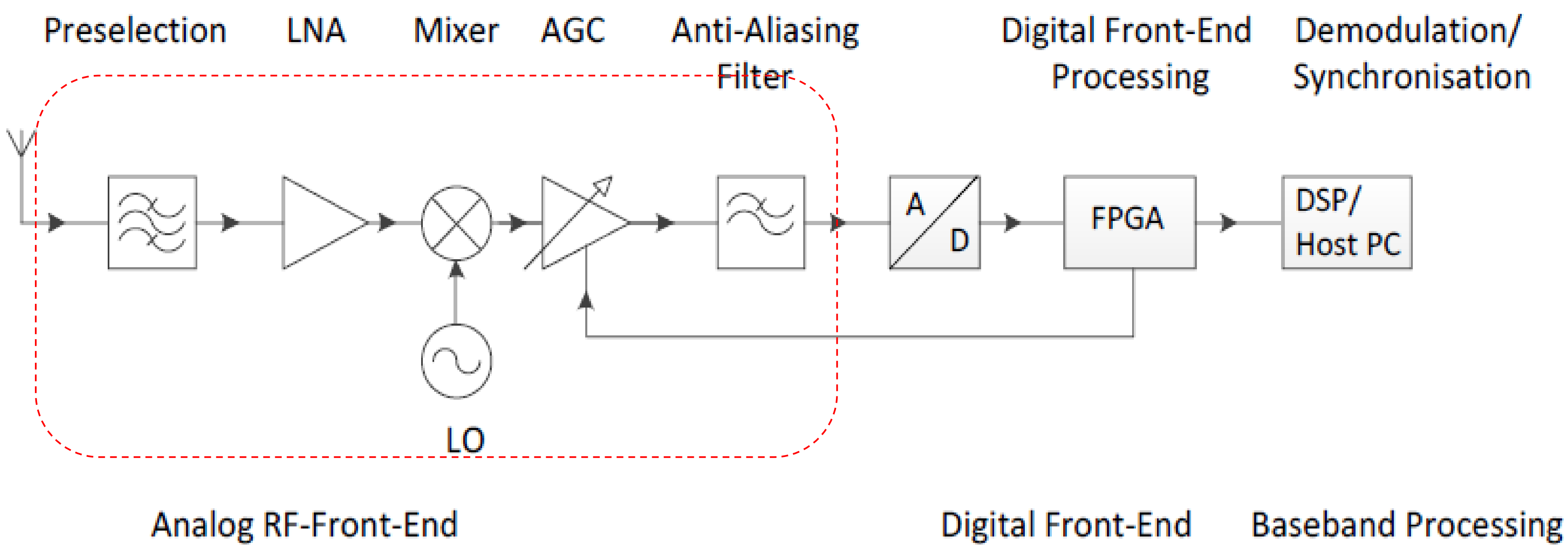
  First publication (February 26-28, 1985):

  Ulrich L. Rohde: Digital HF Radio: A Sampling of Techniques, presented at the Third International Conference on HF Communication Systems and Techniques, London, England, February 26-28, 1985, Classified Session (U.S Secret).

http://en.wikipedia.org/wiki/Software-defined_radio

Typical Microwave Receiver

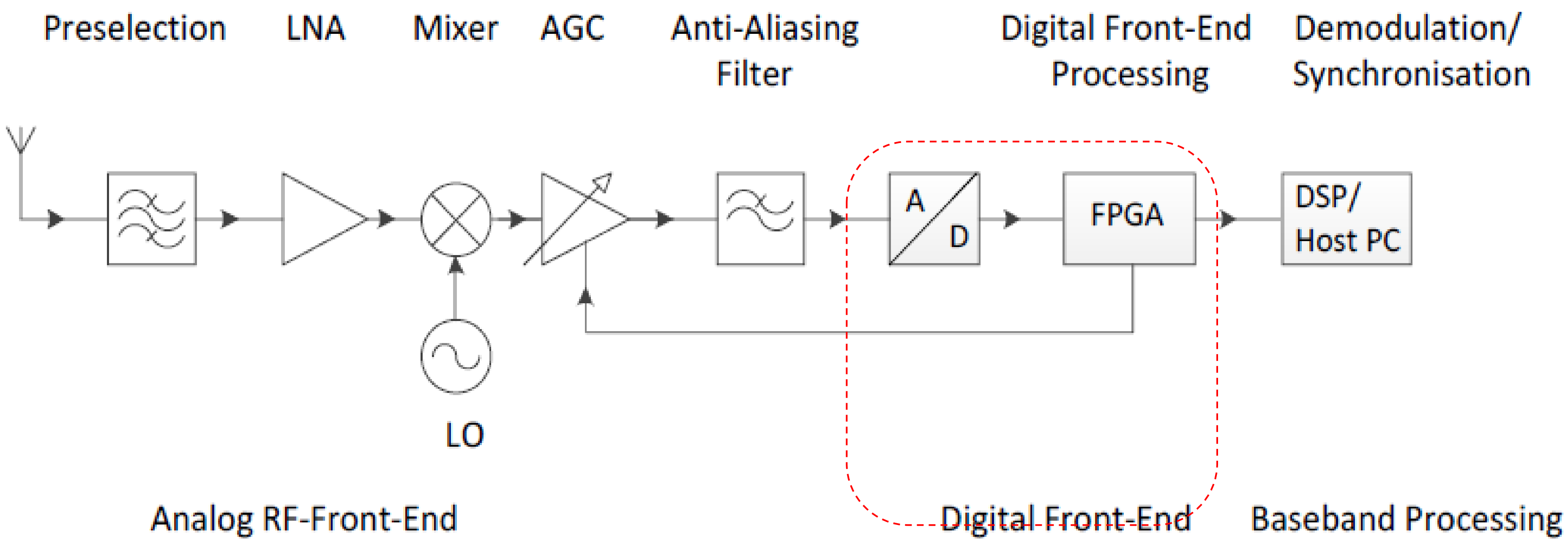
Principal Arrangment for Typical Microwave Receivers



The analog front end is downconverting the RF signals into an IF range <200MHz

Microwave Receiver, Cont‘d.

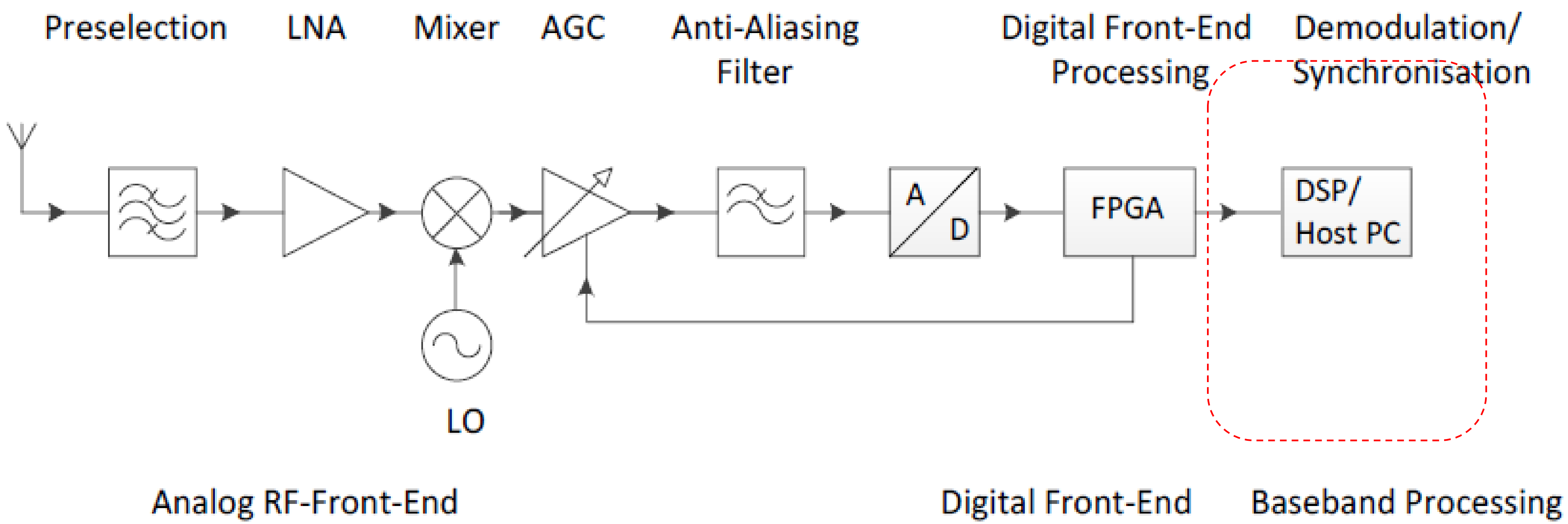
Principal Arrangment for Typical Microwave Receivers



The digital front end consists of an Analog to Digital converter and a digital down- converter to reduce the sample rate down to the bandwidth needed by the application. Sampling rate of AD converters are rising up to 250Msps with resolutions of 14 or 16 bits.

Microwave Receiver, Cont'd.

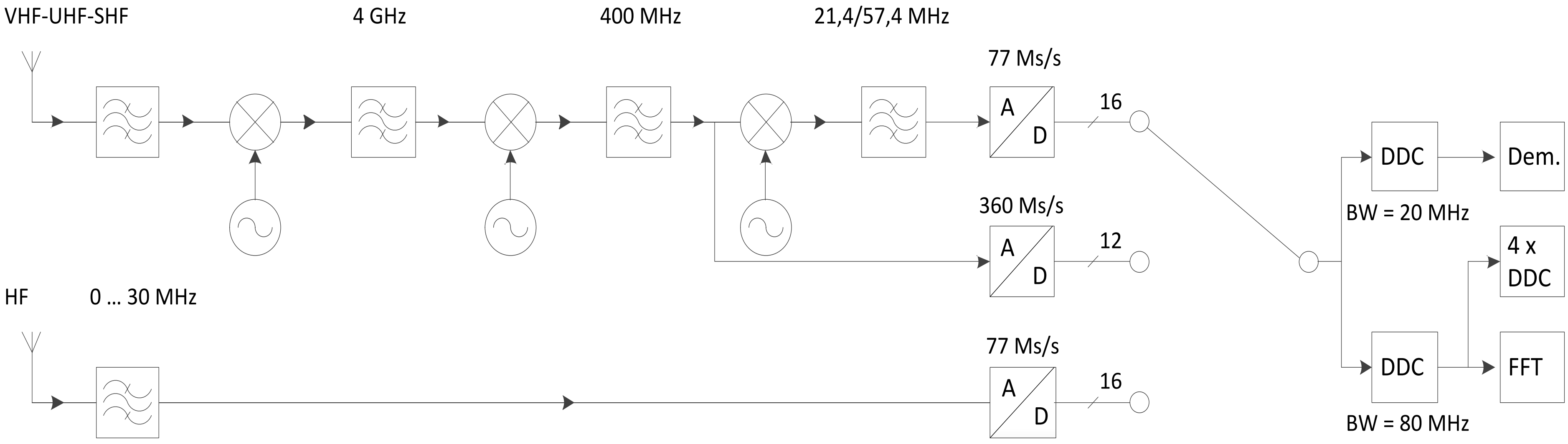
Principal Arrangment for Typical Microwave Receivers



The baseband processing takes over the base band filtering, AGC, demodulation, and the signal regeneration..

Typical Analog Front End

Possible Drawbacks on the Analog Front End



- **Wide band microwave receivers need tripple conversion to prevent image reception**
- **Several expensive and switchable filters are required for pre- and IF-selection**
- **Intermodulation and Oscillator Phase Noise are the main issues**
- **Low noise and high dynamic range are contradictionary**

Image Rejection Mixer

Solution to eliminate tripple Conversion

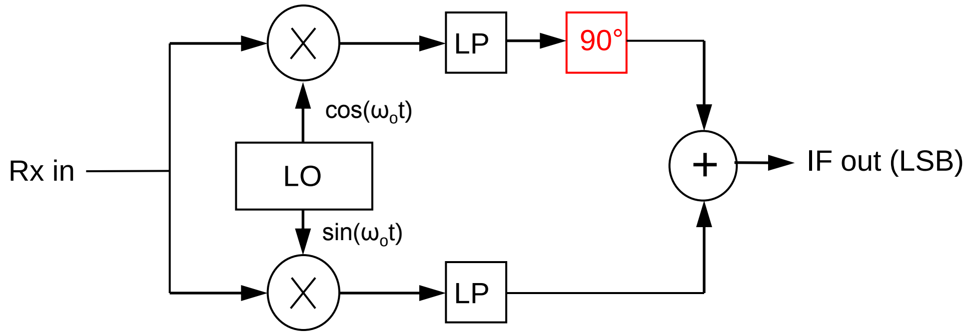
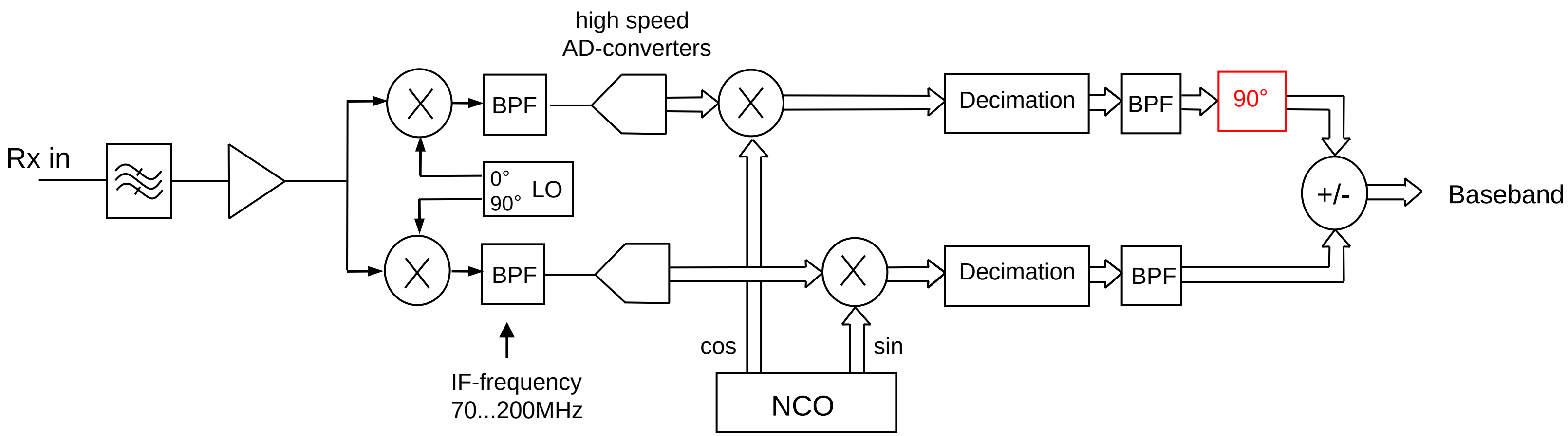


Image Rejection Mixer

- **An analog Image Rejection Mixer is capable to attenuate the Image by 30...40dB**
- **Criterions for the image attenuation are amplitude and phase errors in both branches**
- **The most critical element is the 90° phase shifter, mainly for wide band IF**
- **The SDR technology allows to move the phase shifter from analog into the digital part, where it can be realized nearly ideal by means of a Hilbert Transformer**

Image Rejection Mixer

Solution with a distributed Image Rejection Mixer



- The preselector filters may be wider, as they are no longer used for image rejection
- The digital parts, following the AD converter, can be realized in a FPGA
- In a wide band receiver, the LO can be tuned in steps from up to 10MHz which is simplifying the PLL loop filter design. The fine tuning will be done by the NCO
- The image rejection can be further improved by calibration algorithms in the digital part to values up to 80dB

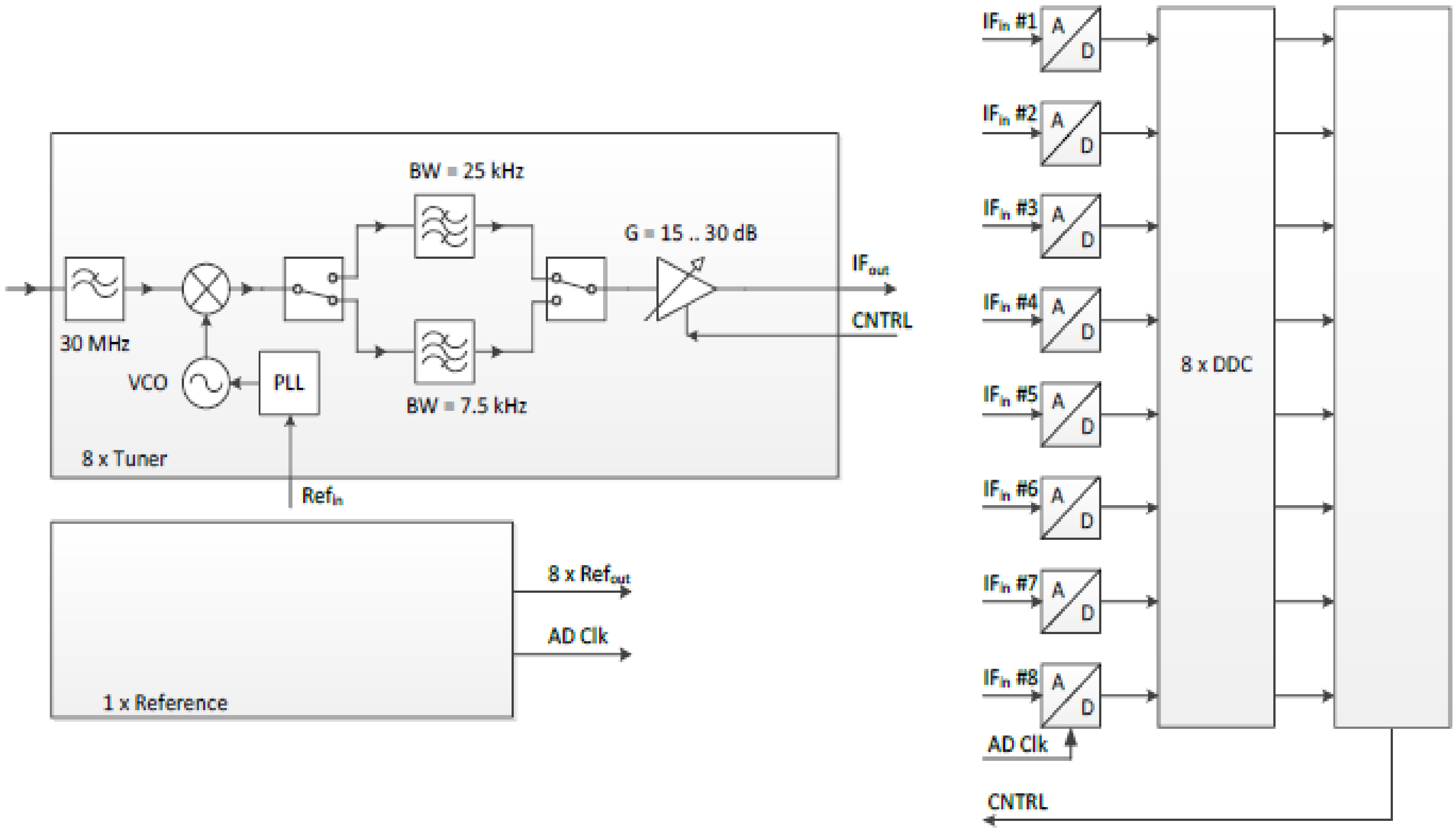
Microwave Monitoring Receiver

Requirements on a Monitoring Receiver

- Fast detection of unknown signals
- Search for activities over wide frequency ranges
- Monitoring of individual frequencies, lists frequency ranges
- Measurement of spectral characteristics of very short or rarely occurring signals
- Storage of activities
- Triggering of further activities after a signal is detected
- Demodulation of communications and/or transfer of demodulated signals for processing
- Integration into civil and military dedicated systems
- Homing, i.e. localization of signal sources and direction finding
- Simple coverage measurements
- Measurements in line with ITU recommendations

Receiver, Cont'd.

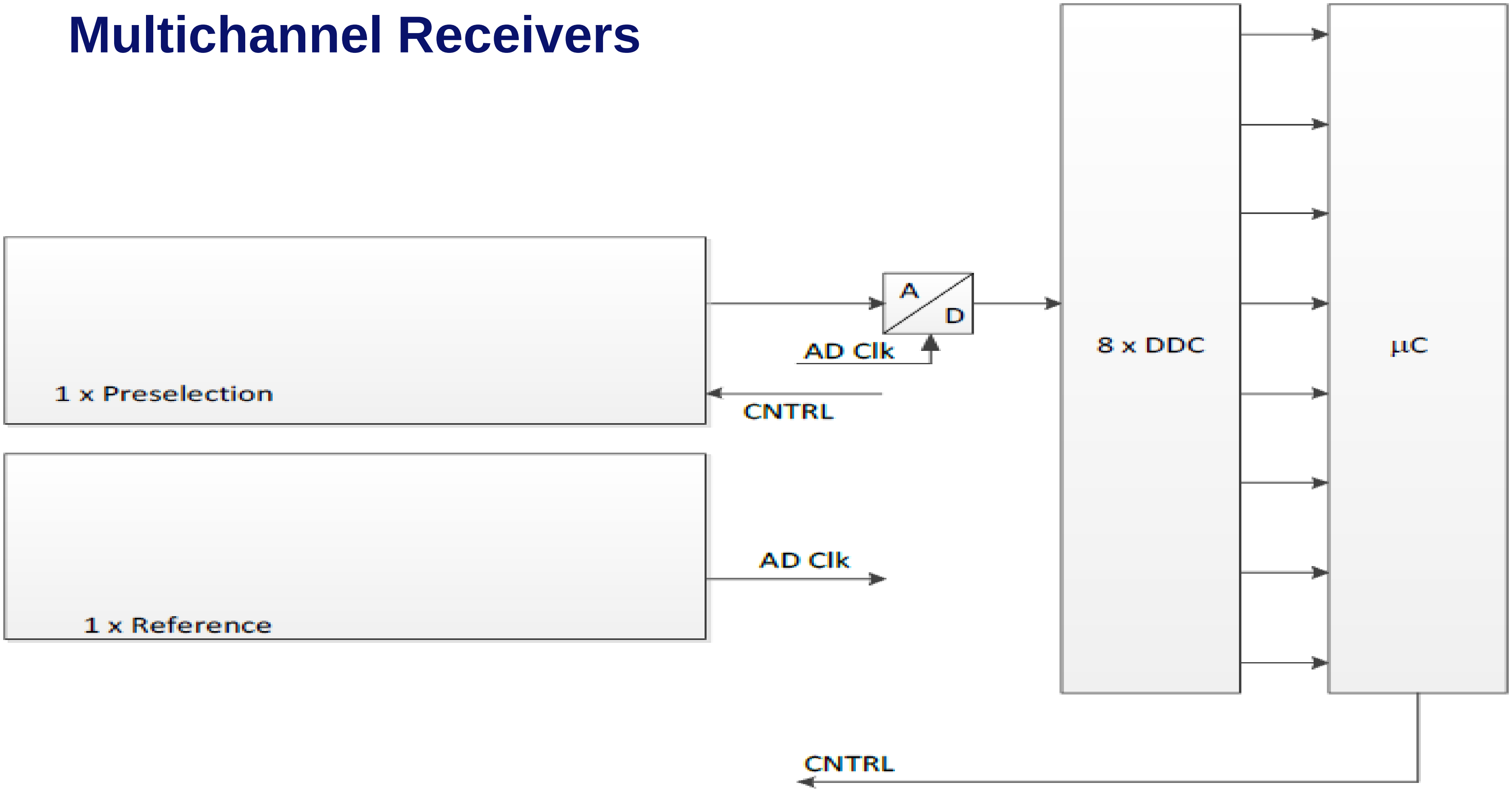
Multichannel Receivers



N - channel Receiver with N analog front ends

Receiver, Cont‘d.

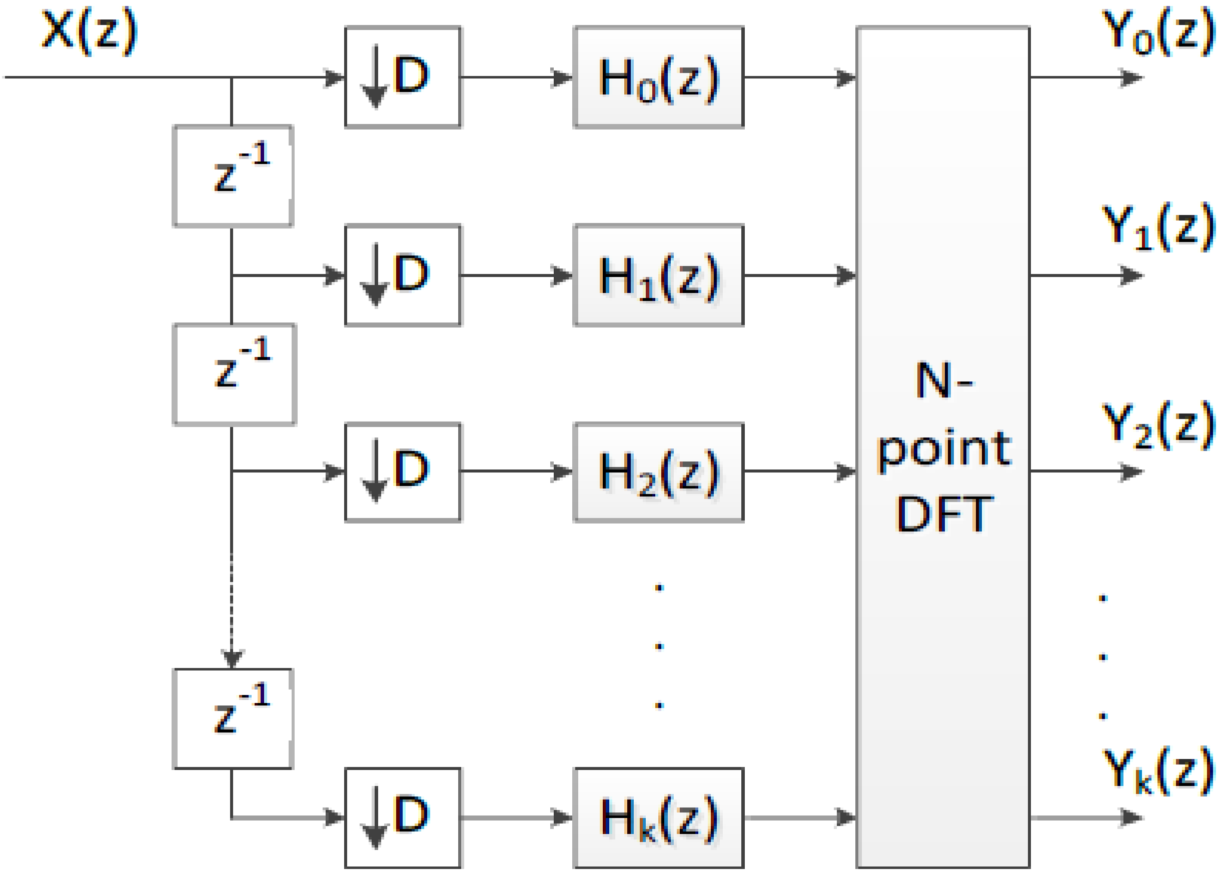
Multichannel Receivers



N - channel Receiver with only one analog front end and N digital down converters. The channel frequencies must be allocated inside the preselector passband.

Receiver, Cont‘d.

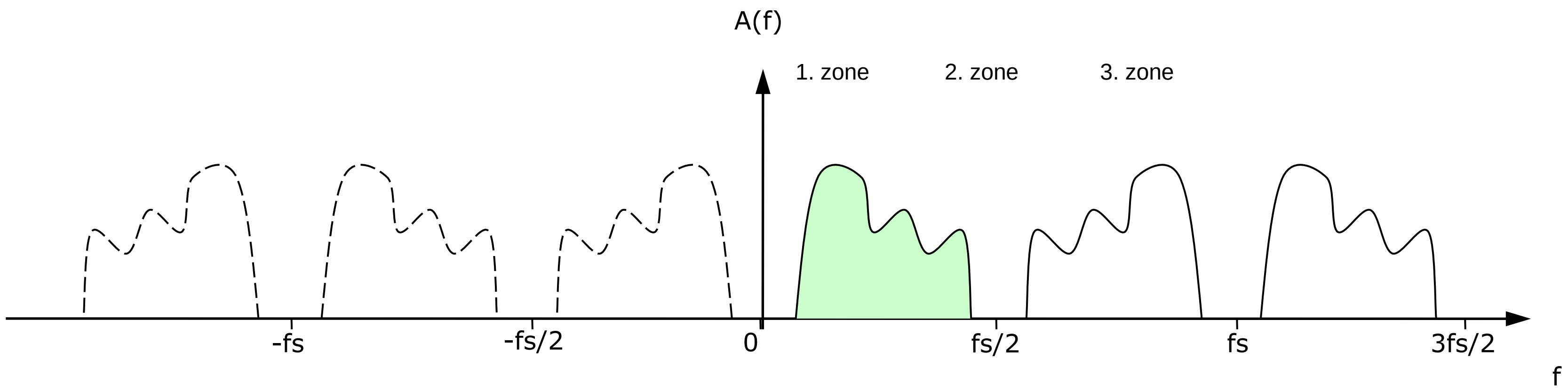
Multichannel Receivers



If all channels are equally spaced, then a Polyphase Filterbank can replace the multiple channels in the downconverter

Typical Characteristics of Sampled Systems

Important Characteristics of sampled Systems



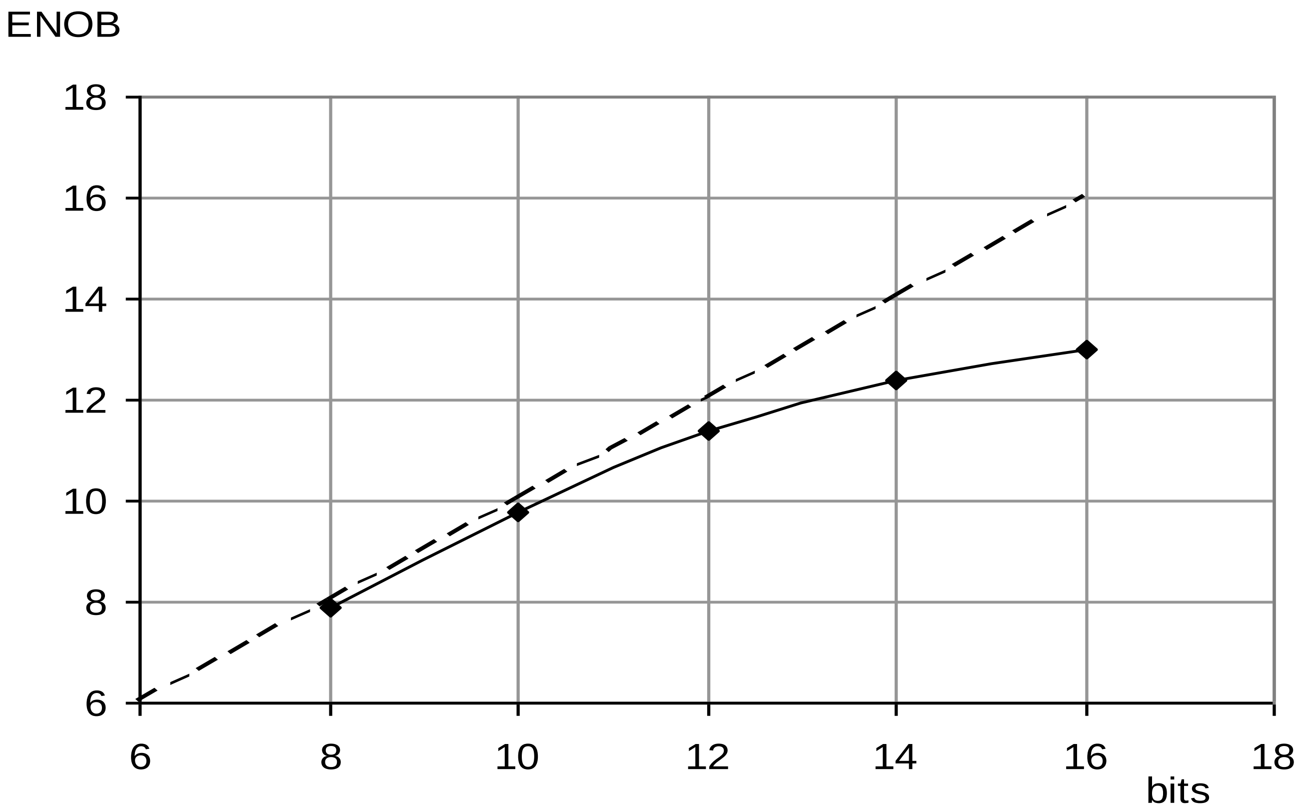
The Sampling Theorem (Nyquist / Shannon)

- **A bandlimited signal can be reconstructed, when B < fs/2**
- **Due to aliasing, replicas in all Nyquist zones will occur**
- **The aliasing effect can be used to sample a bandlimited signal B in a higher Nyquist zone (bandpass- or undersampling)**

B = (n – 1) · fs/2 ... n · fs/2 **whereas n is the zone (1,2, …)**

Typical Characteristics of AD Converters

Characteristics of AD Converters



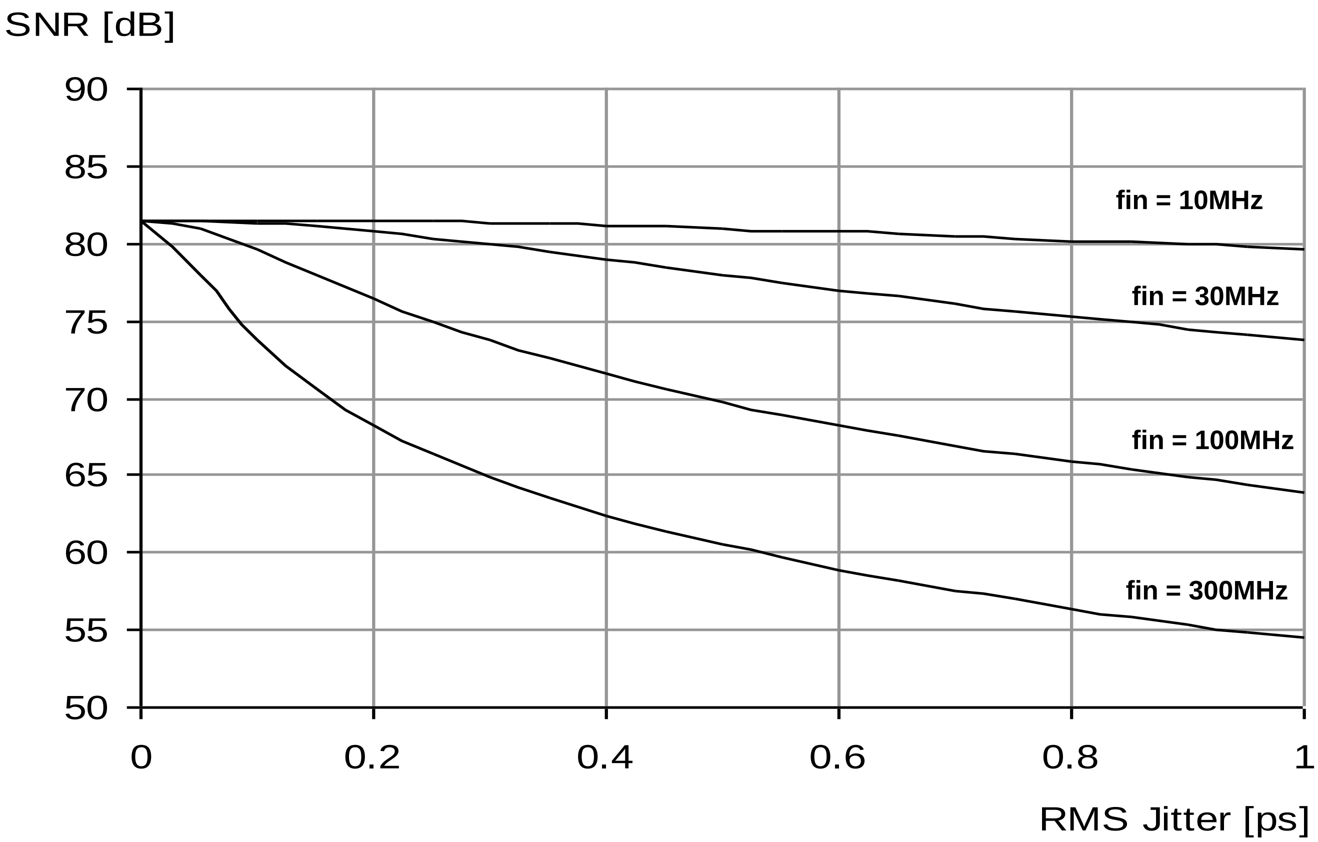
ENOB: the Effective usable Number Of Bits

$$SNR_{eff} = 1.76dB + ENOB \cdot 6.02dB$$

(measured in B = fs/2)

Characteristics of AD Converters, Cont‘d.

Characteristics of AD Converters

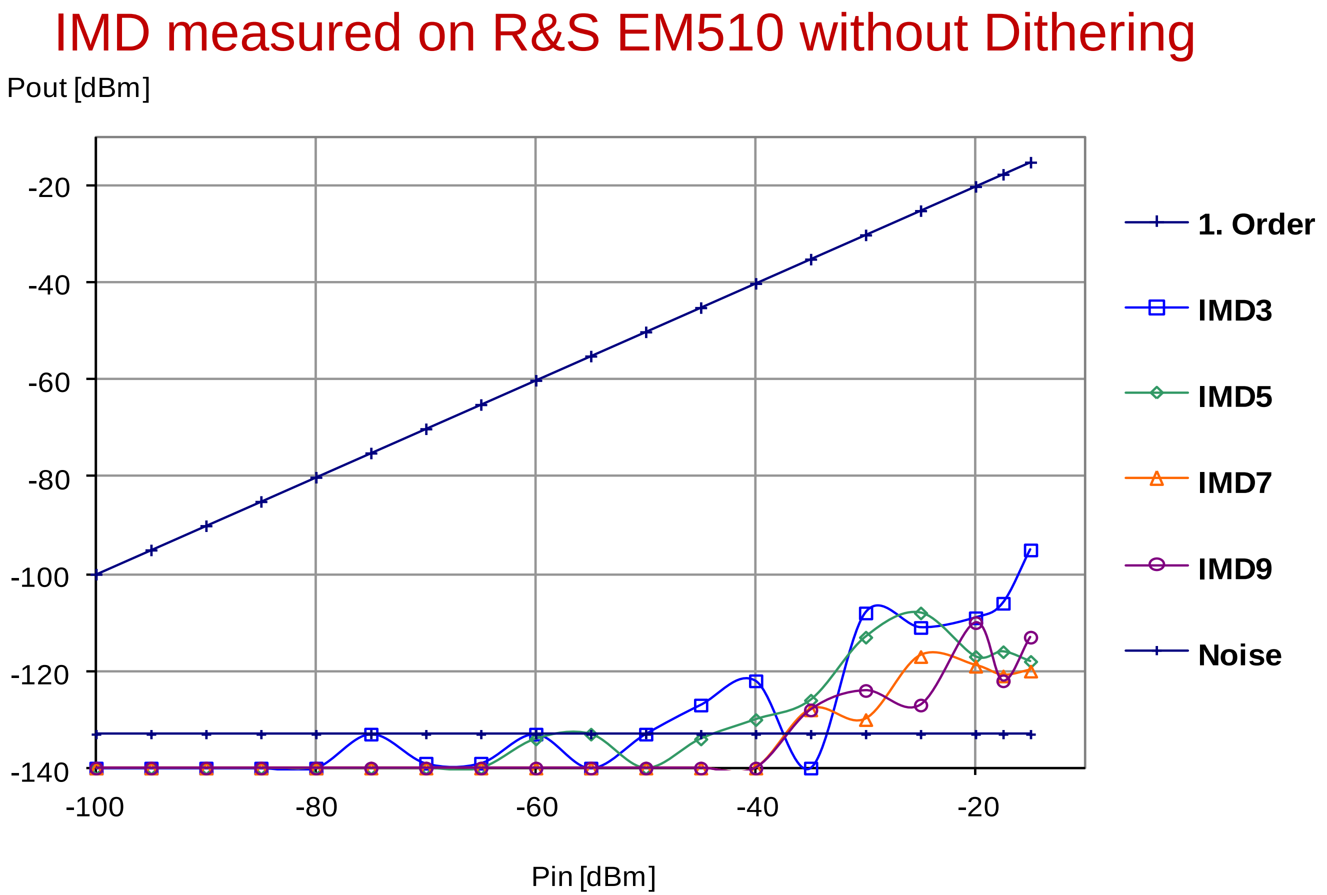


Degradation of SNR by clock jitter

→ very important when applying undersampling!

Characteristics of AD Converters

Important Characteristics of AD converters

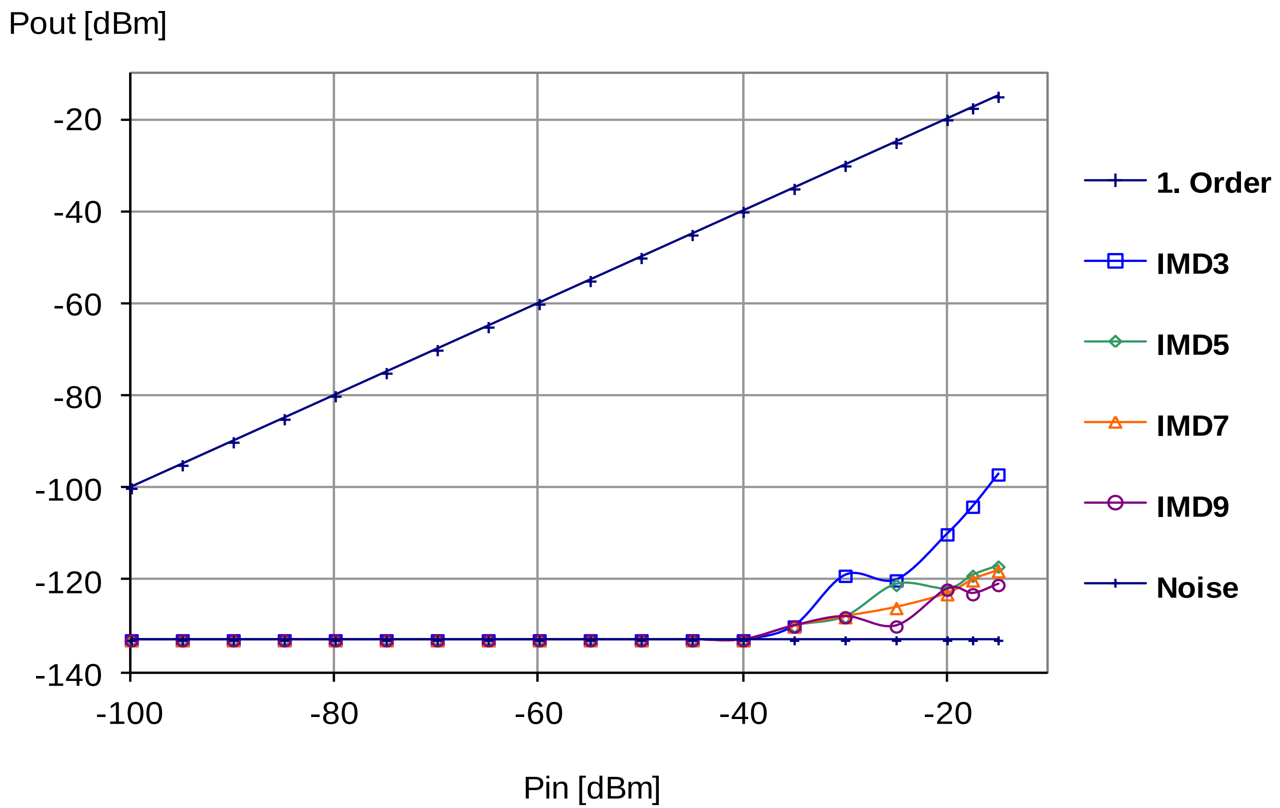


Higher order intermodulation products as a function of the input signal. The known relationship of n·dB/dB (n = order of IM) can not be applied. Therefore an Intercept point cannot be calculated. In practice, the IM is measured with two tones on -7dBr

Characteristics of AD Converters

Important Characteristics of AD converters

IMD measured on R&S EM510, with Dithering



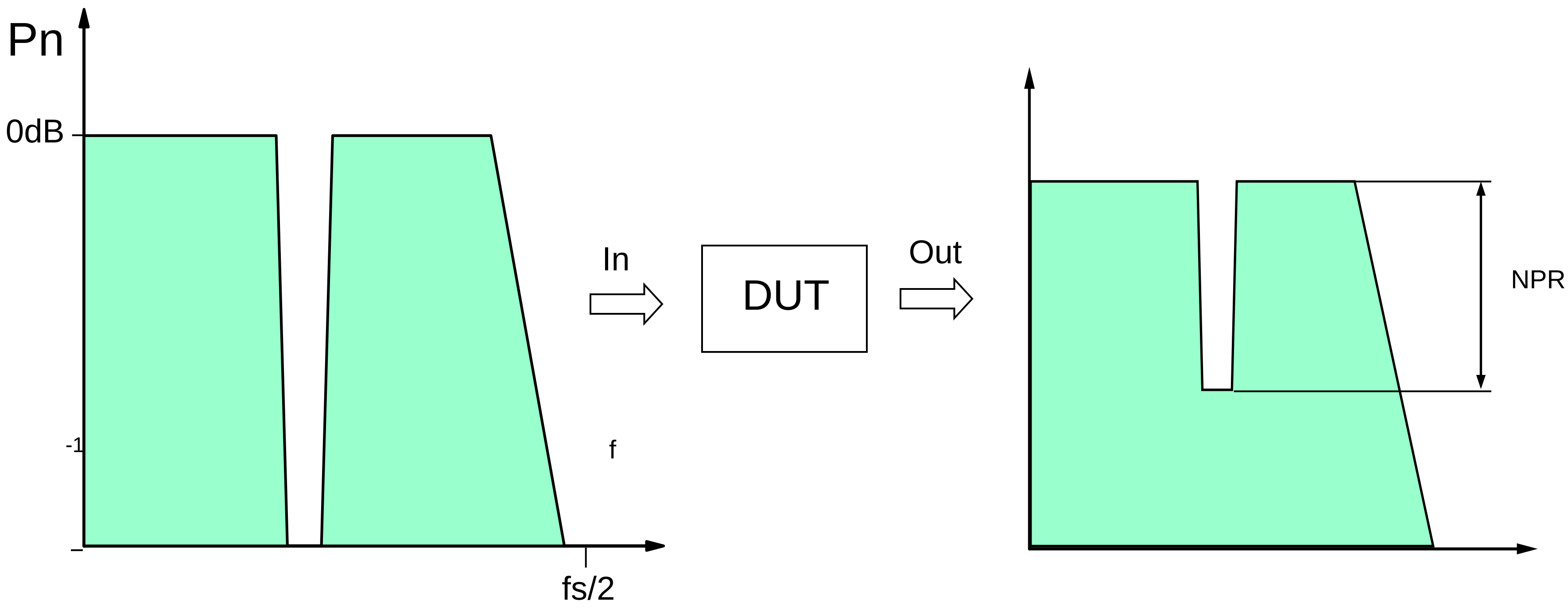
Applying dithering noise has the effect, that the discontinuities are no longer periodic and therefore the spuriies are reduced.

Characteristics of AD Converters

Important Characteristics of AD converters

Altrernative Methode for IM measuring

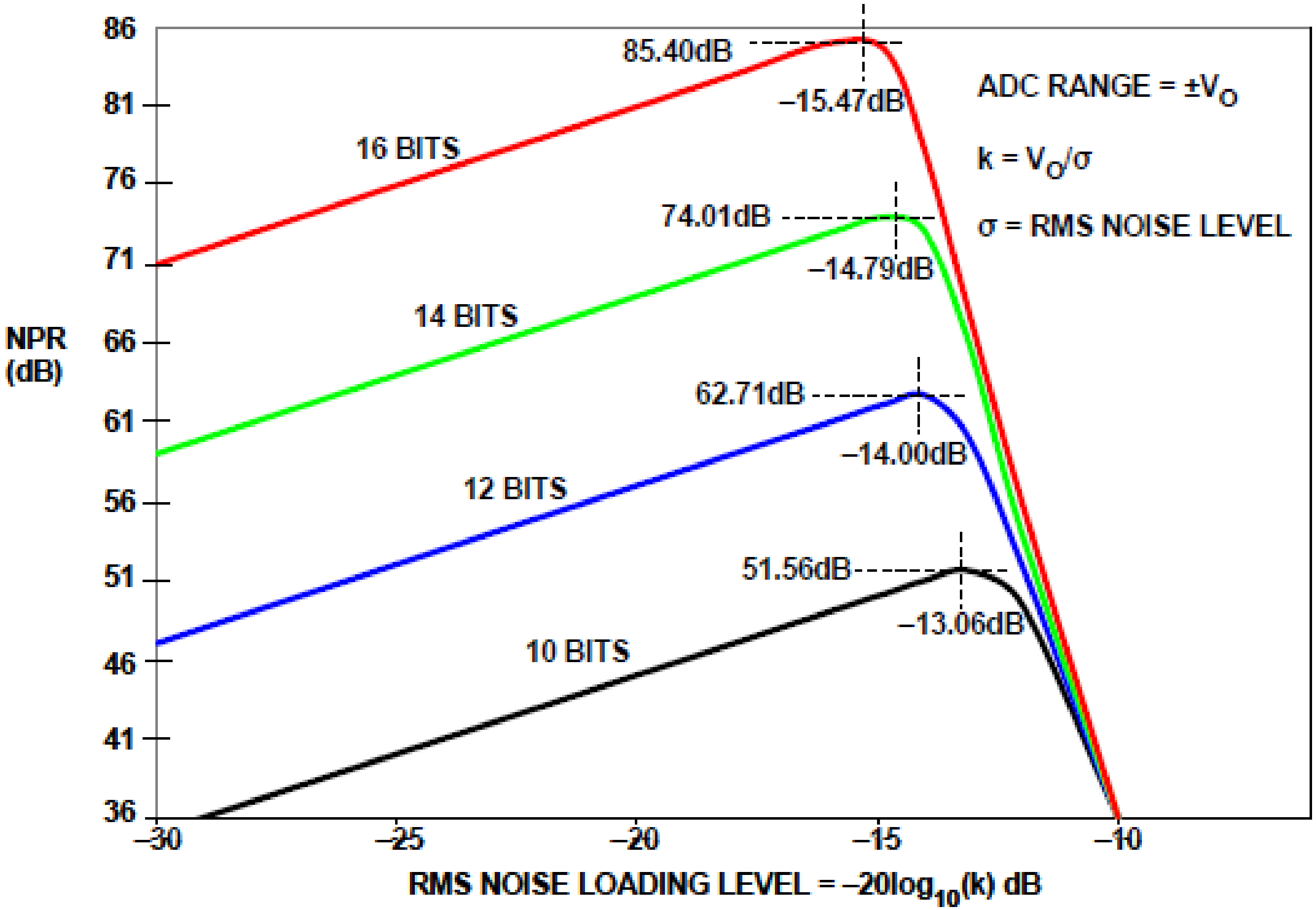
The Noise Power Ratio



The NPR methode reflects the true impact of intermodulation from any order

Characteristics of AD Converters

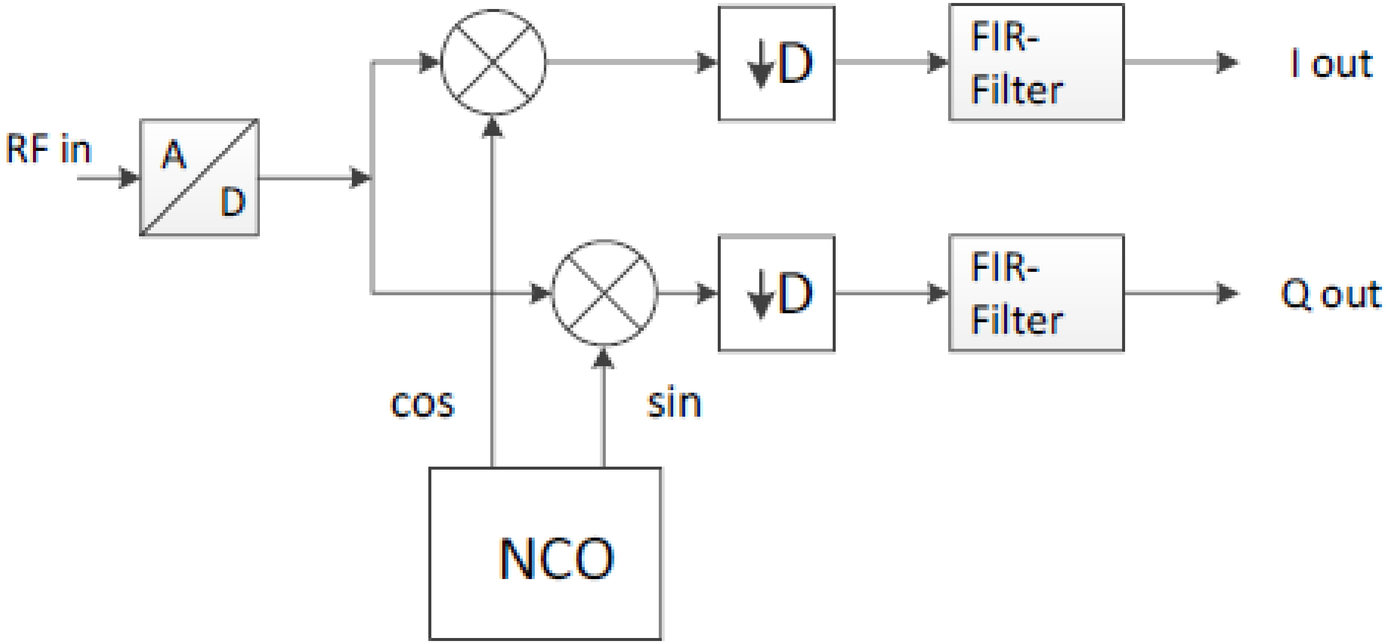
Important Characteristics of AD converters



Theoretical NPR for 10, 12,14 and 16bit AD converter

Down Converters

Digital Down Converter

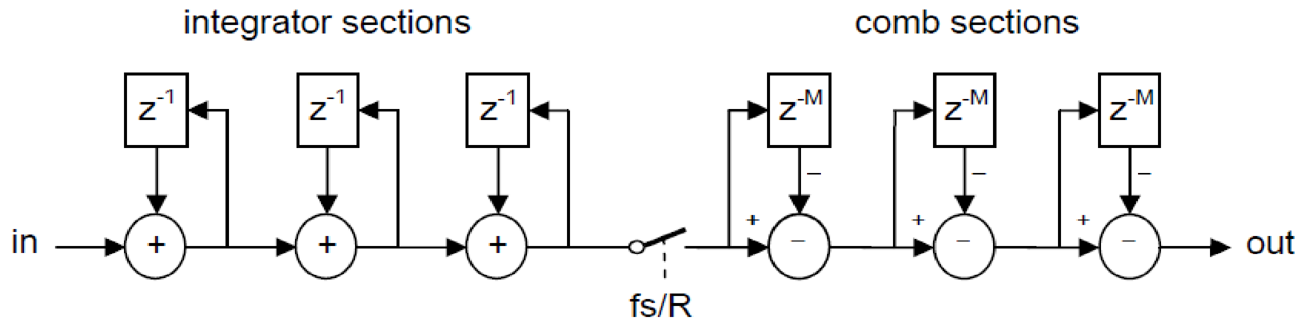


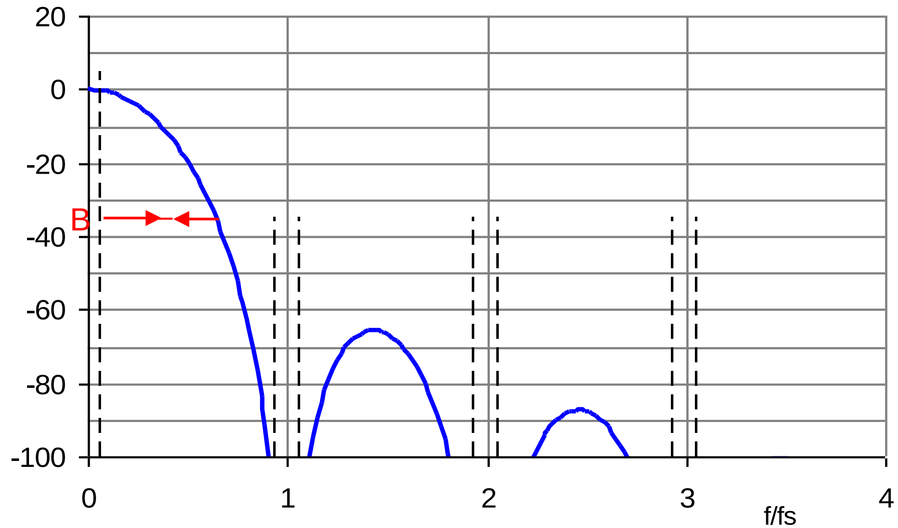
The digital down converter includes:

- a numerically oscillator (NCO)
- a complex IQ-mixer to convert the IF down to approx. 0Hz (zero-IF)
- several decimation filter stages for reducing the sampling rate
- final lowpass FIR-filters (Finite Impulse Response)

Down Converters

Digital Down Converter





$$|H(f)| = \left| \frac{\sin(\pi \cdot M \cdot f)}{\sin(\pi \cdot f / R)} \right|^N$$

R: decimation factor

N: filter order (sections)

M = 1 or 2

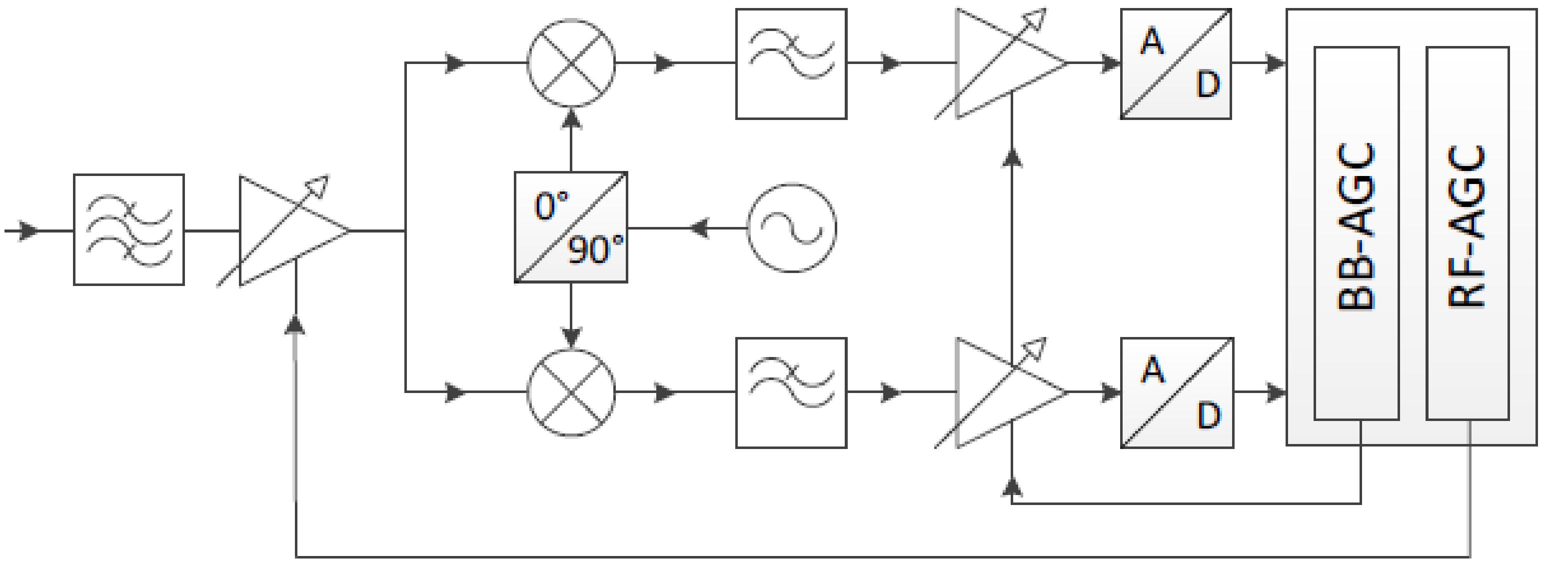
fs: input sample rate

B = fs / R

CIC-Filter with R = 16, N = 5, M = 1 (CIC: Cascaded Integrator Comb)

Automatic Gain Control

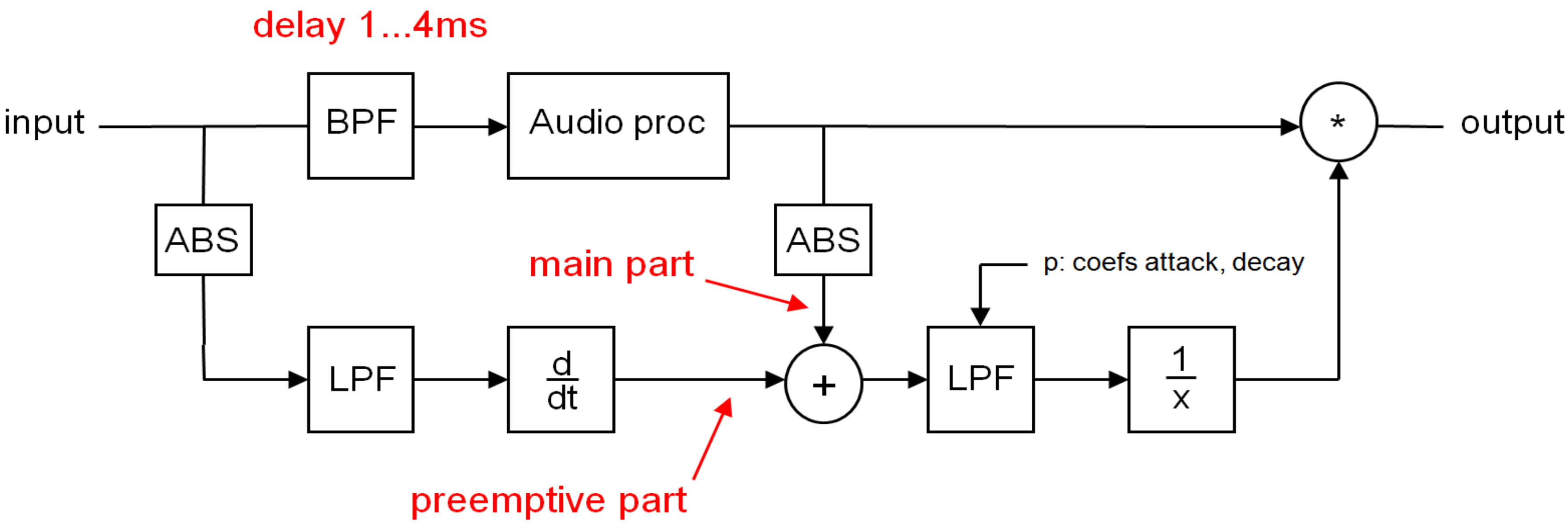
Automatic Gain Control



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.

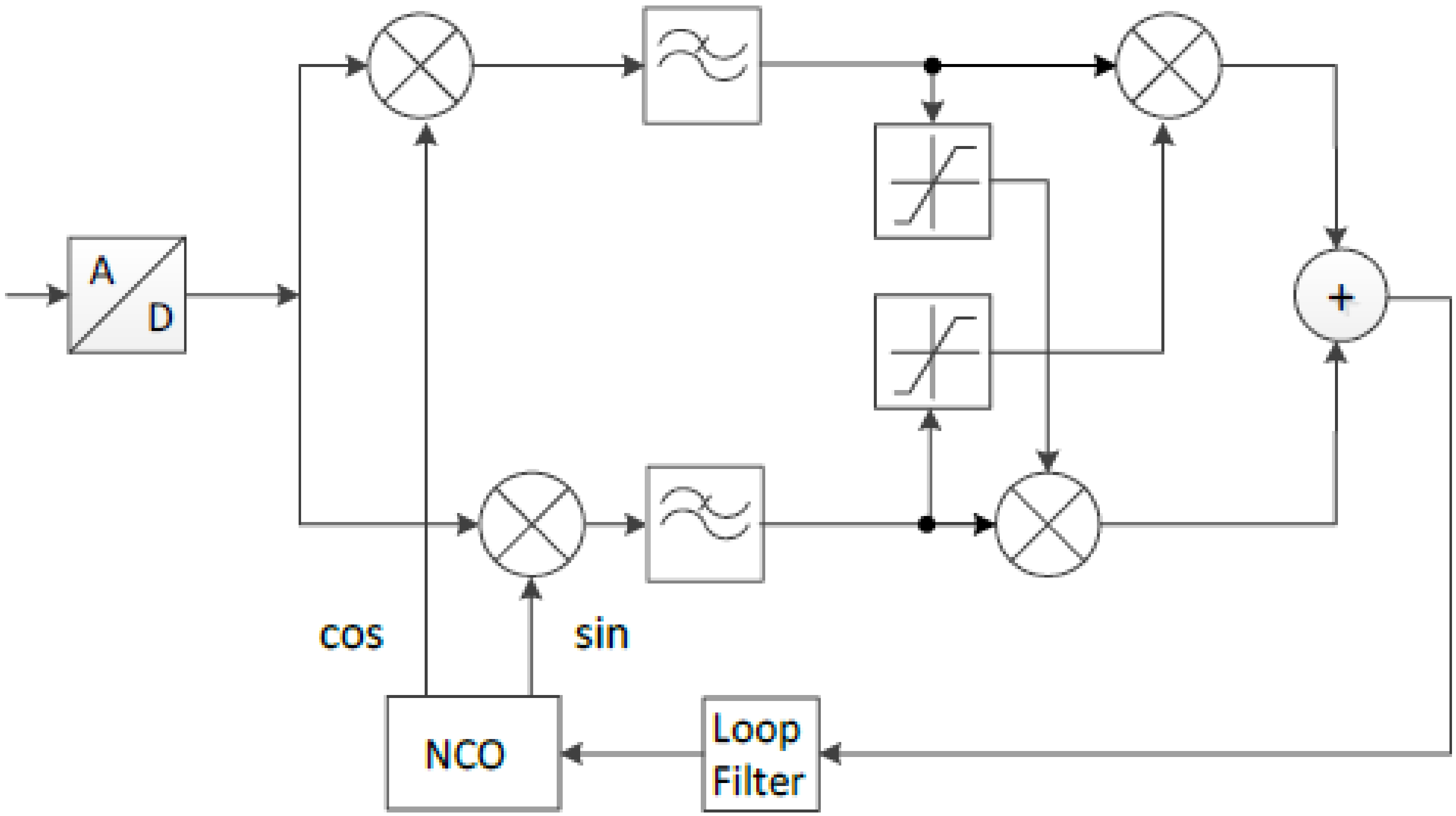
Automatic Gain Control



The main AGC control is realized near the of the signal processing chain as a feed forward control.

Carrier Recovery

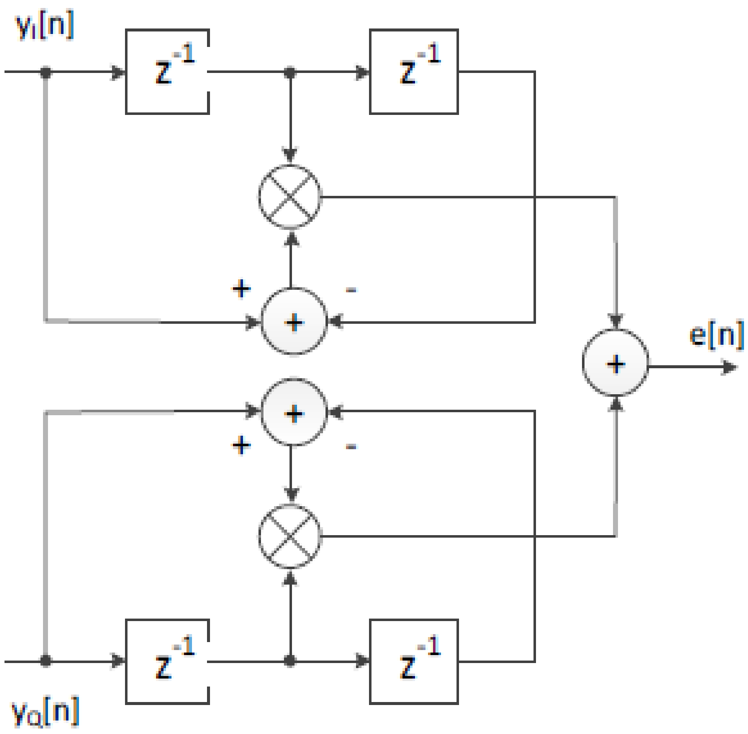
Carrier Recovery for Data Communication

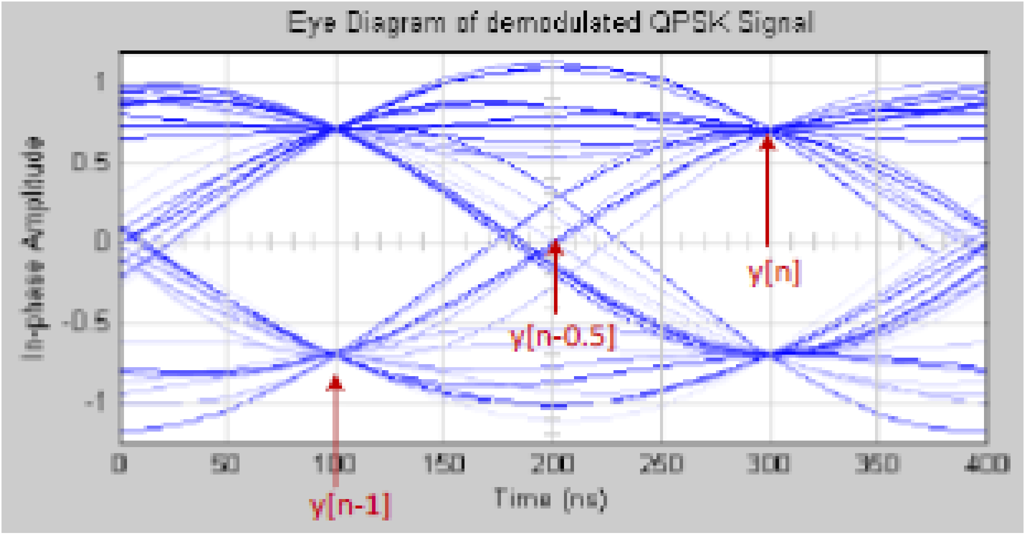


Example for the carrier synchronisation for a QPSK modulated carrier.

Data Clock Extraction

Data clock extraction for Data Communication

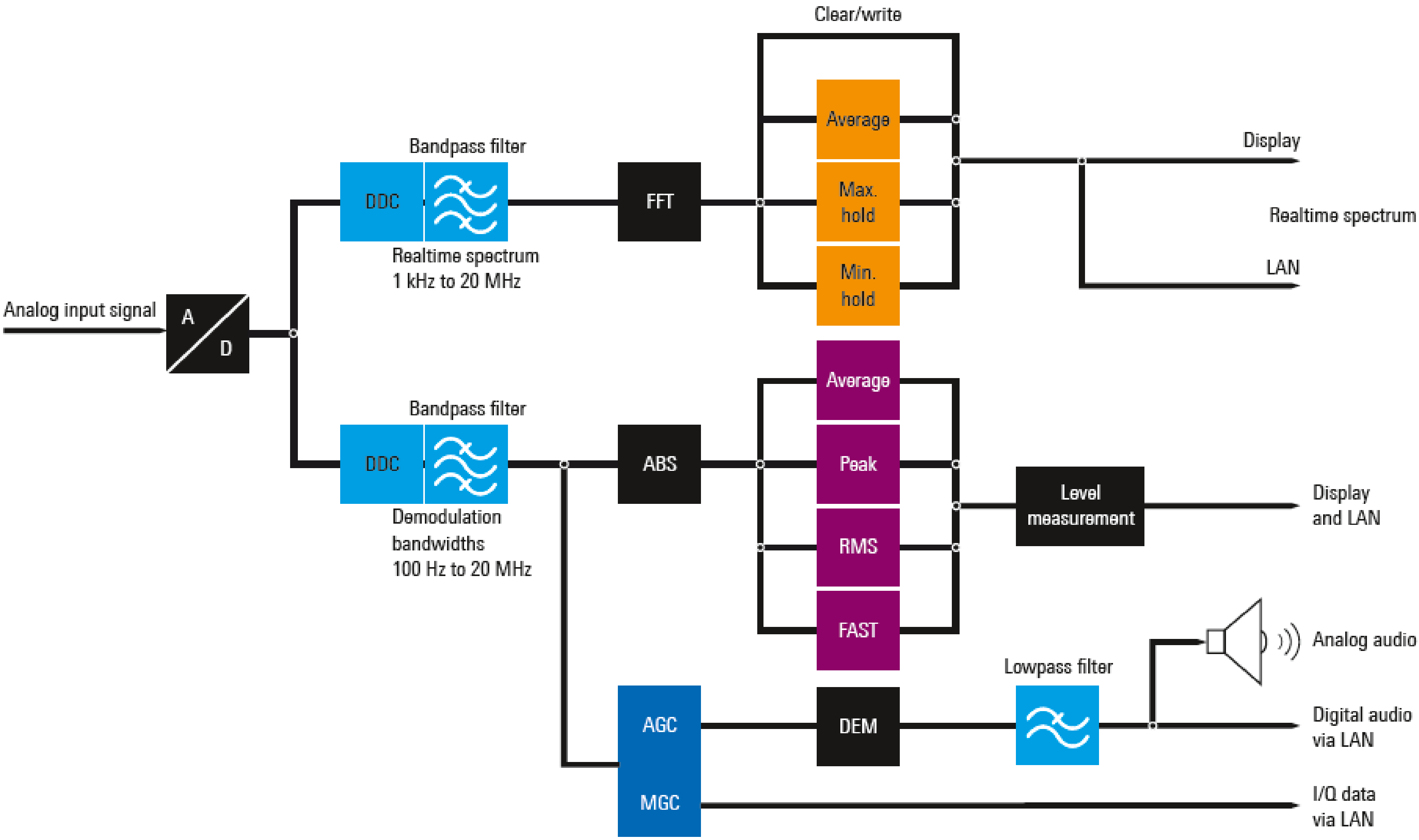




Example for a Timing Error Detector for a QPSK modulated signal according to Gardner.

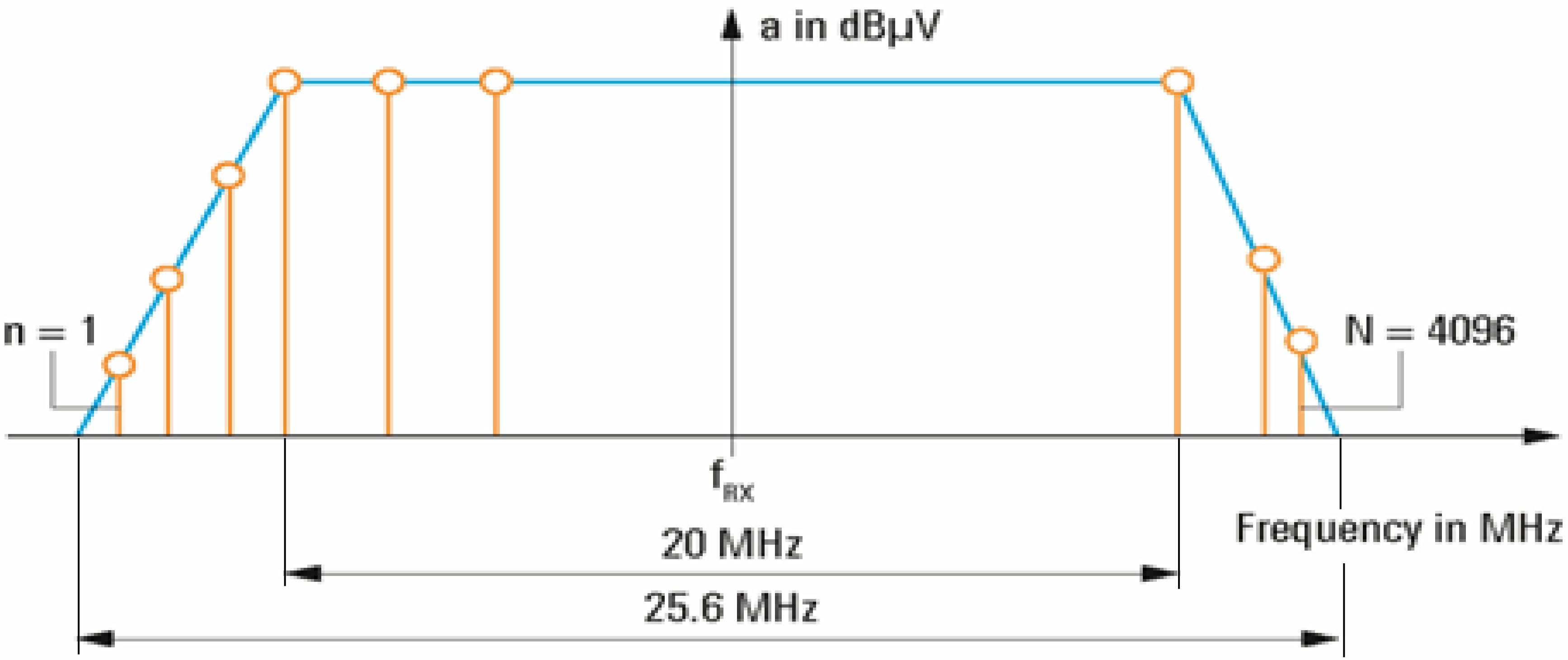
Widebnad Monitoring Receiver

R&S ESMD Wide Band Monitoring Receiver



Spectrum Analysis in Receiver

Spectrum Analysis in Communication Receivers



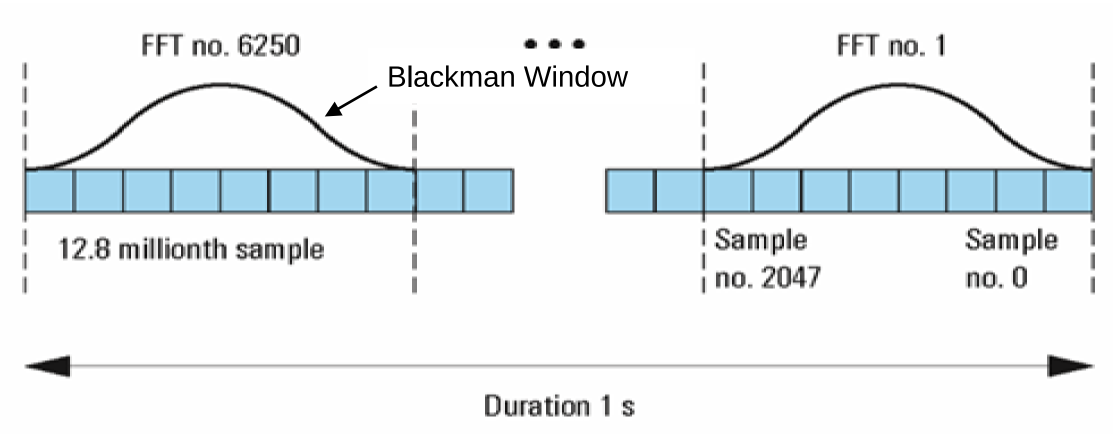
The actual usable bandwidth is reduced by a factor k compared with the sampling rate fs:

$$B_{eff} = fs / k$$

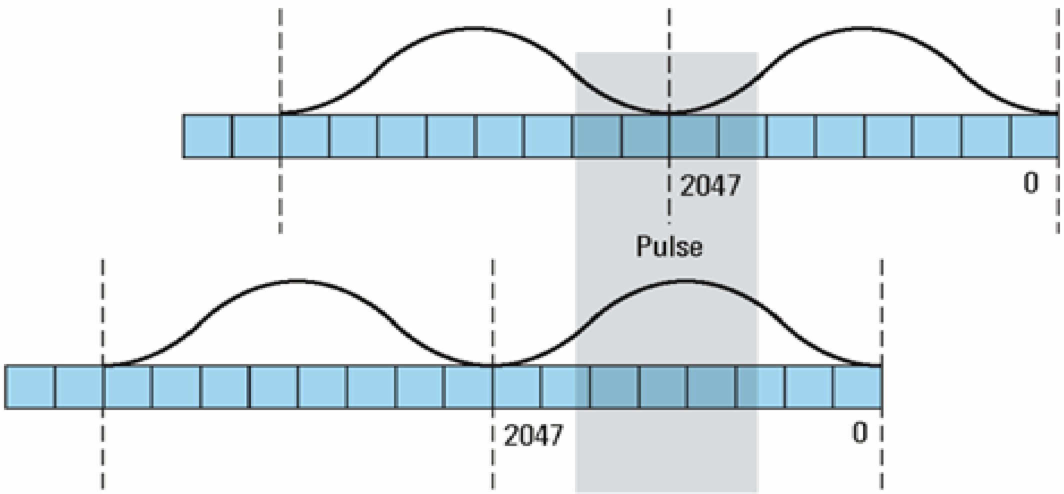
In this exemple k = 1.28

Spectrum Analysis in Receiver, Cont'd.

Spectrum Analysis in Communication Receivers



An fs = 12.8Msps allows to process 6250 FFTs per second



Due to the applied window function, the capability to detect short pulses at both ends of the window is reduced

Solution: overlapping FFTs

Spectrum Analysis in Receiver, Cont‘d.

Spectrum Analysis in Communication Receivers

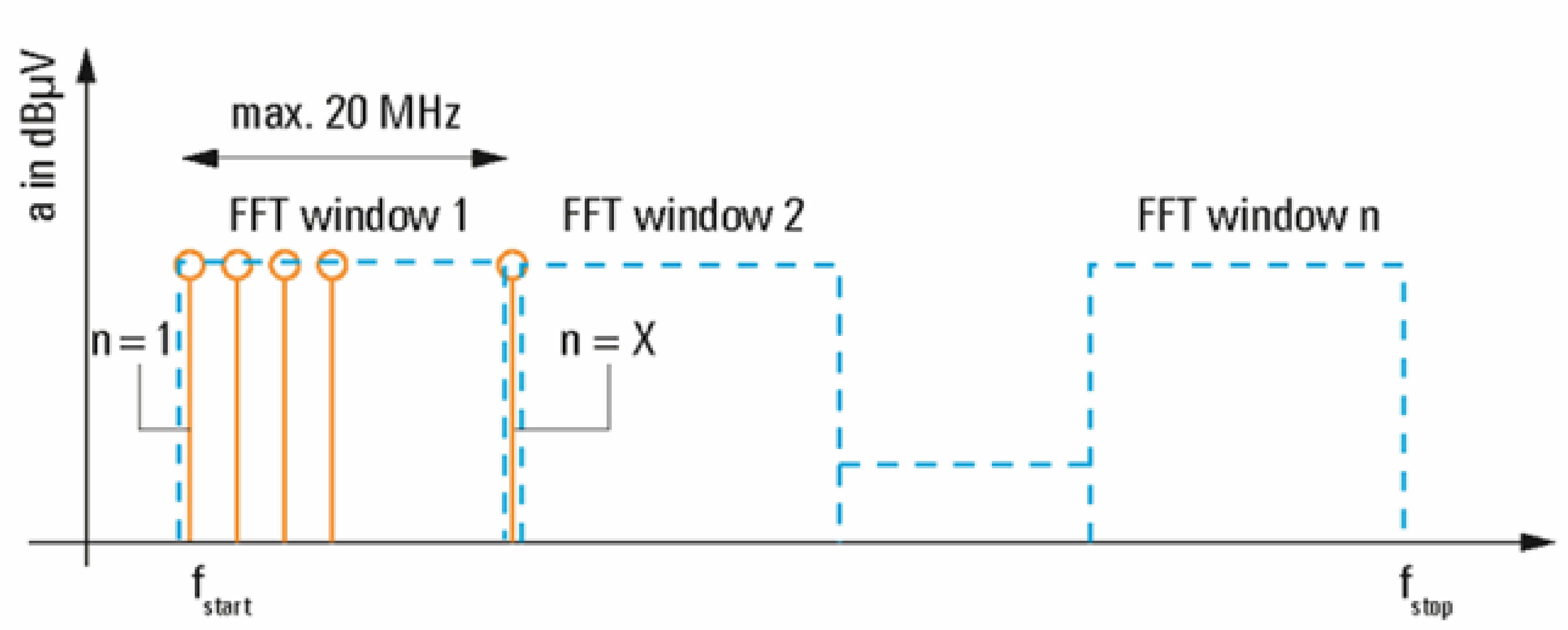
Computing Power for overlapping 2048 bins FFT and fs = 12.8Msps:

≈ 2GFLOPs (Floating Point Operations)

Internal computing power of the R&S®ESMD		
Frequency -resolution in kHz	80 MHz realtime -bandwidth	
	Spectra per second	Time resolution in is
25	25 000	40
50	50 000	20
100	100 000	10
500	500 000	2
2000	2 000 000	0.5

Spectrum Analysis in Receiver, Cont'd.

Spectrum Analysis in Communication Receivers

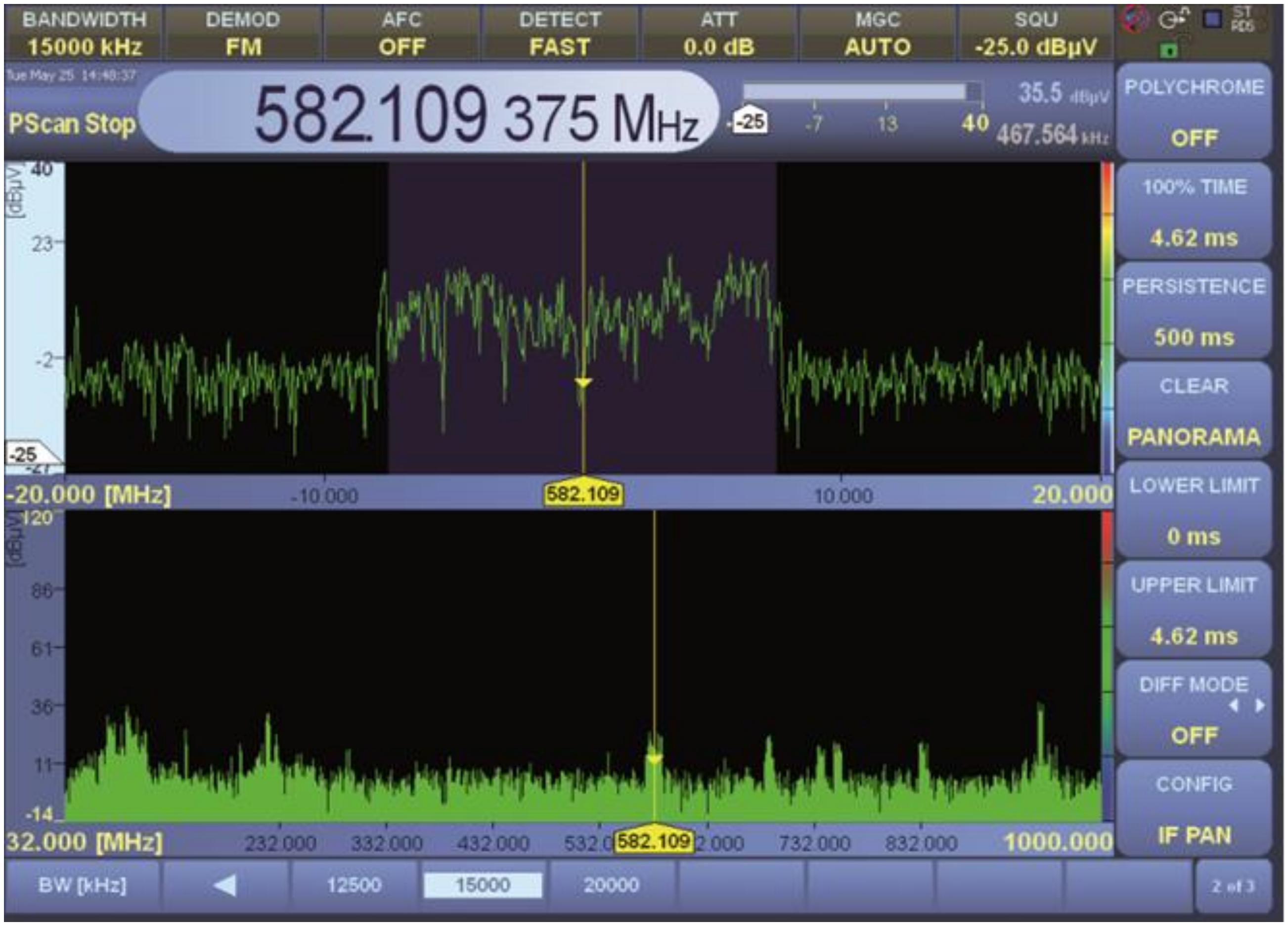


Panorama Function with N consecutive FFT slices

⇨ for any bandwidth, but lacks in time resolution

Spectrum Analysis in Receiver, Cont‘d.

Spectrum Analysis in Communication Receivers

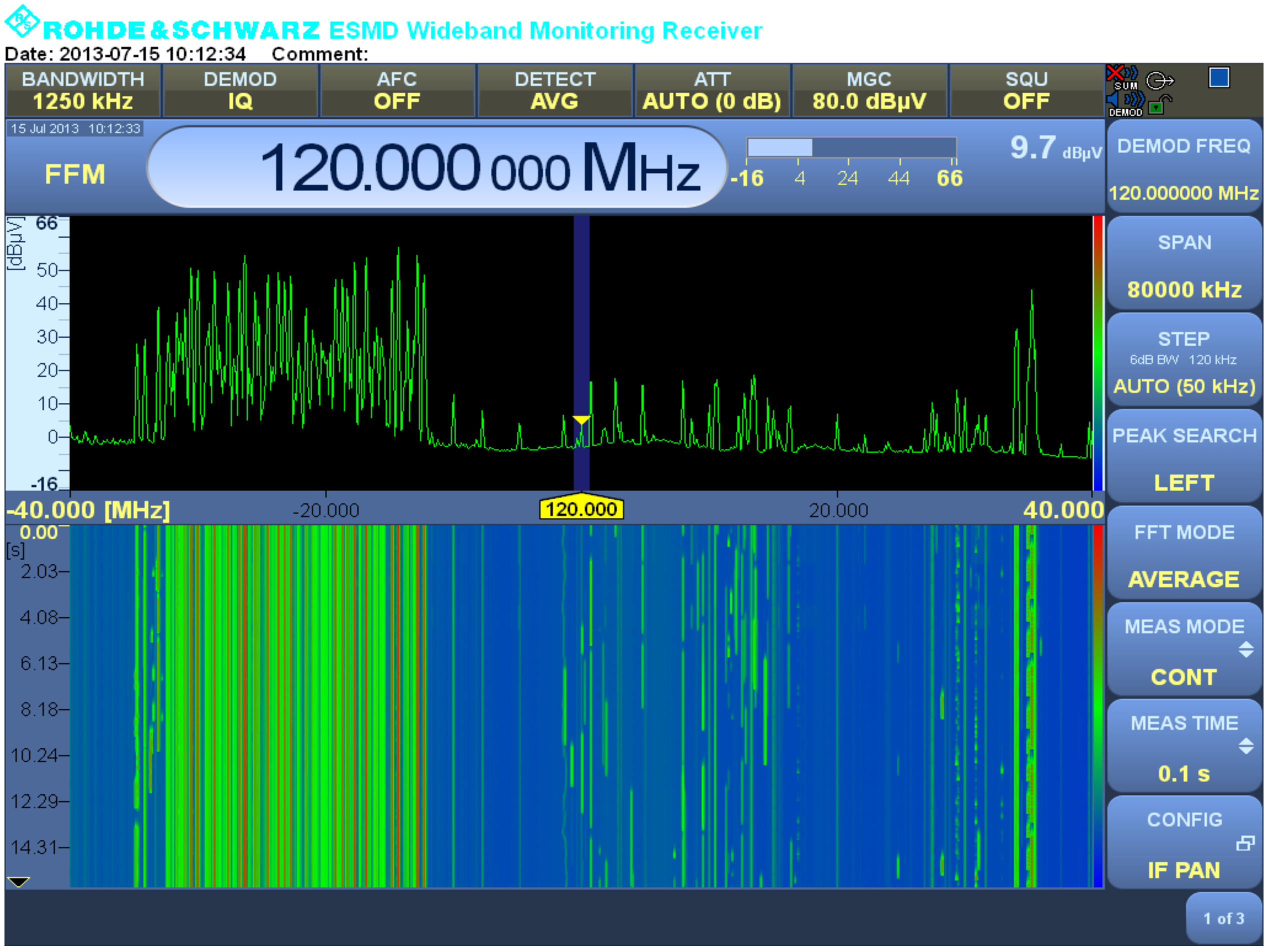


Narrowband Analysis

Wideband Analysis

Spectrum Analysis in Communication Receiver

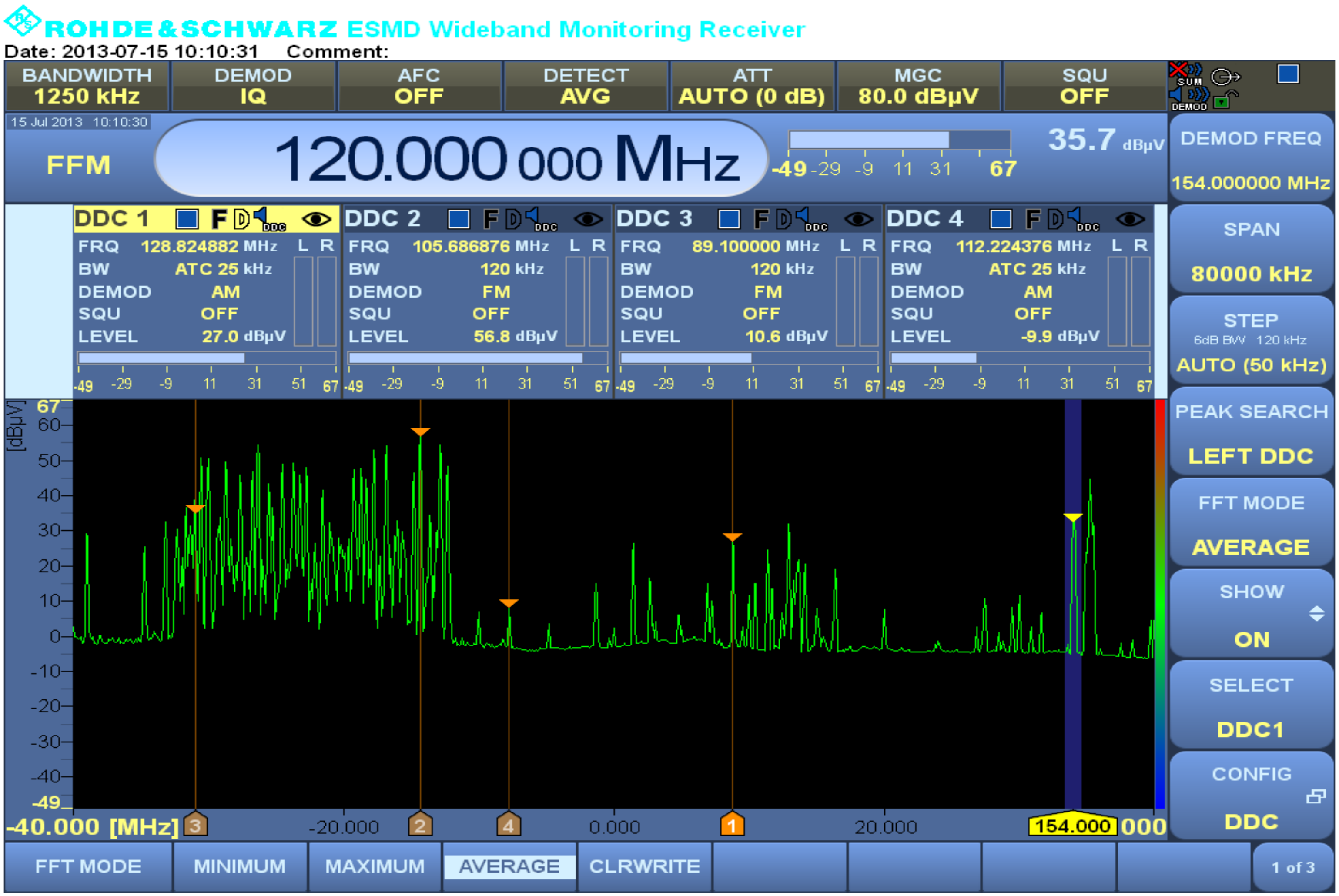
Proof of Available Dynamic Range



Aircraft Radio Communication Receiver can be monitored abd demodulated in the presence of strong FM Radio signal

Spectrum Analysis in Communication Receiver

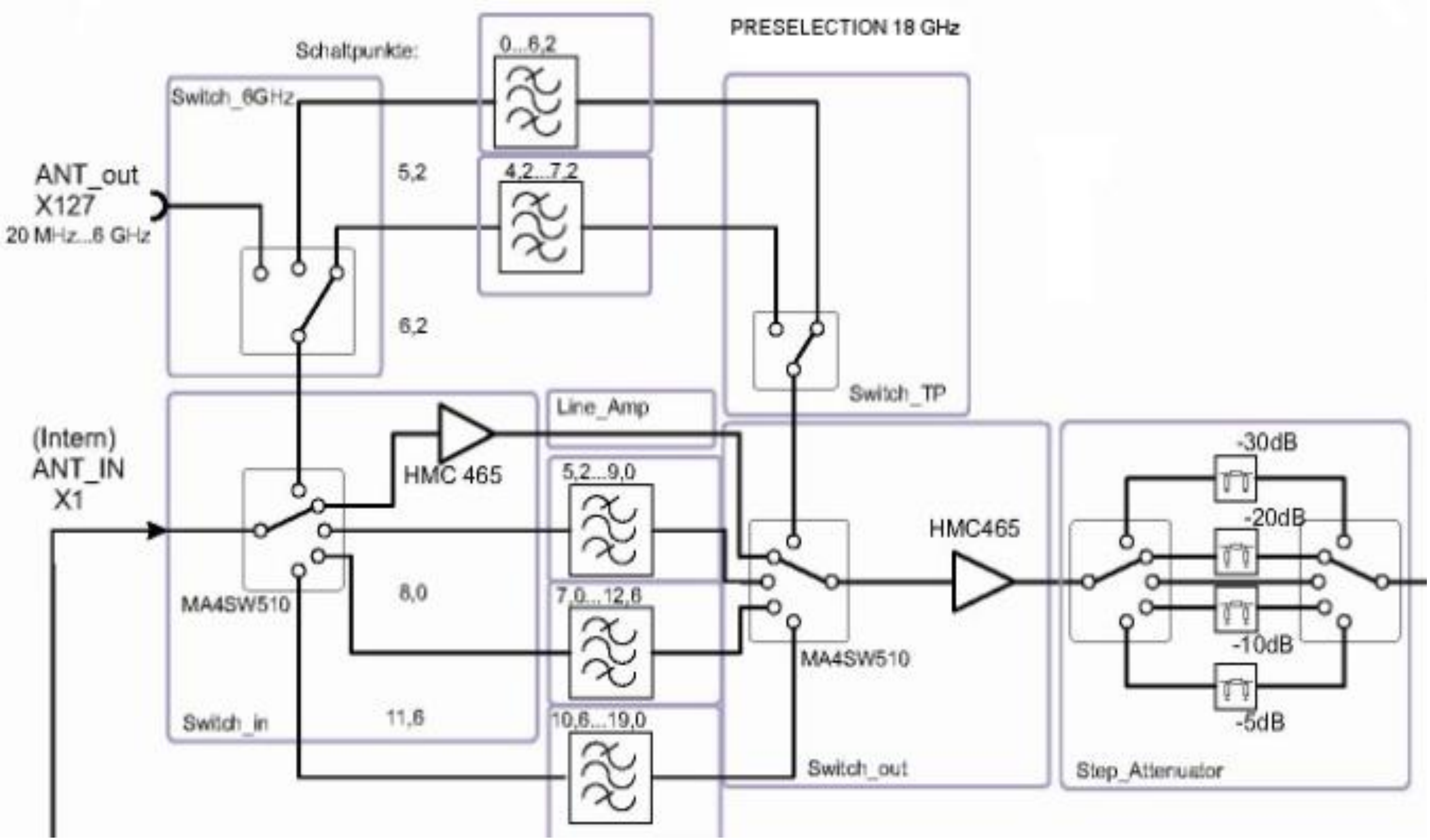
Multichannel (4) Operation



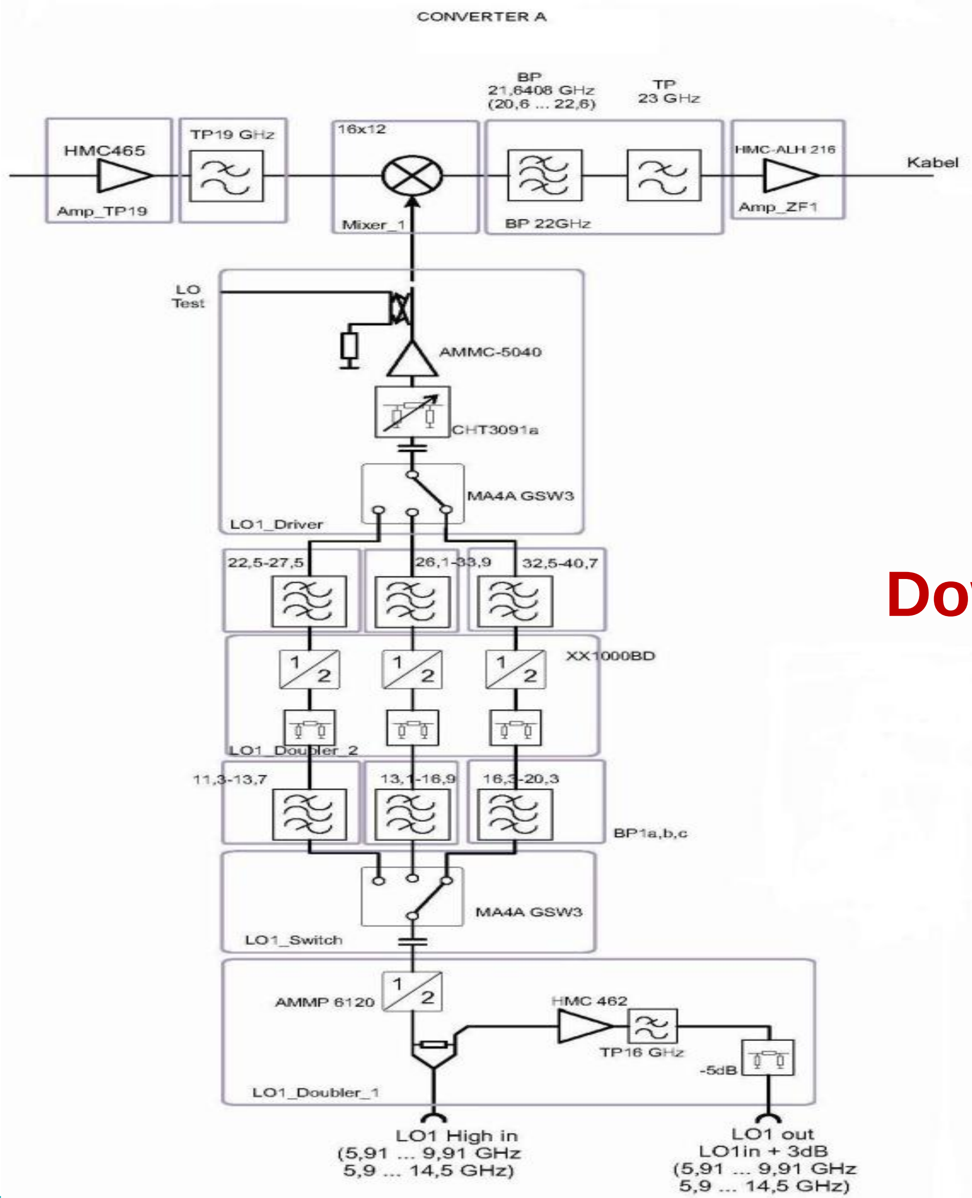
All 4-Channels can be anlayzed

Typical Architecture of Communication Receiver

Filter portion of the front-end of the receiver

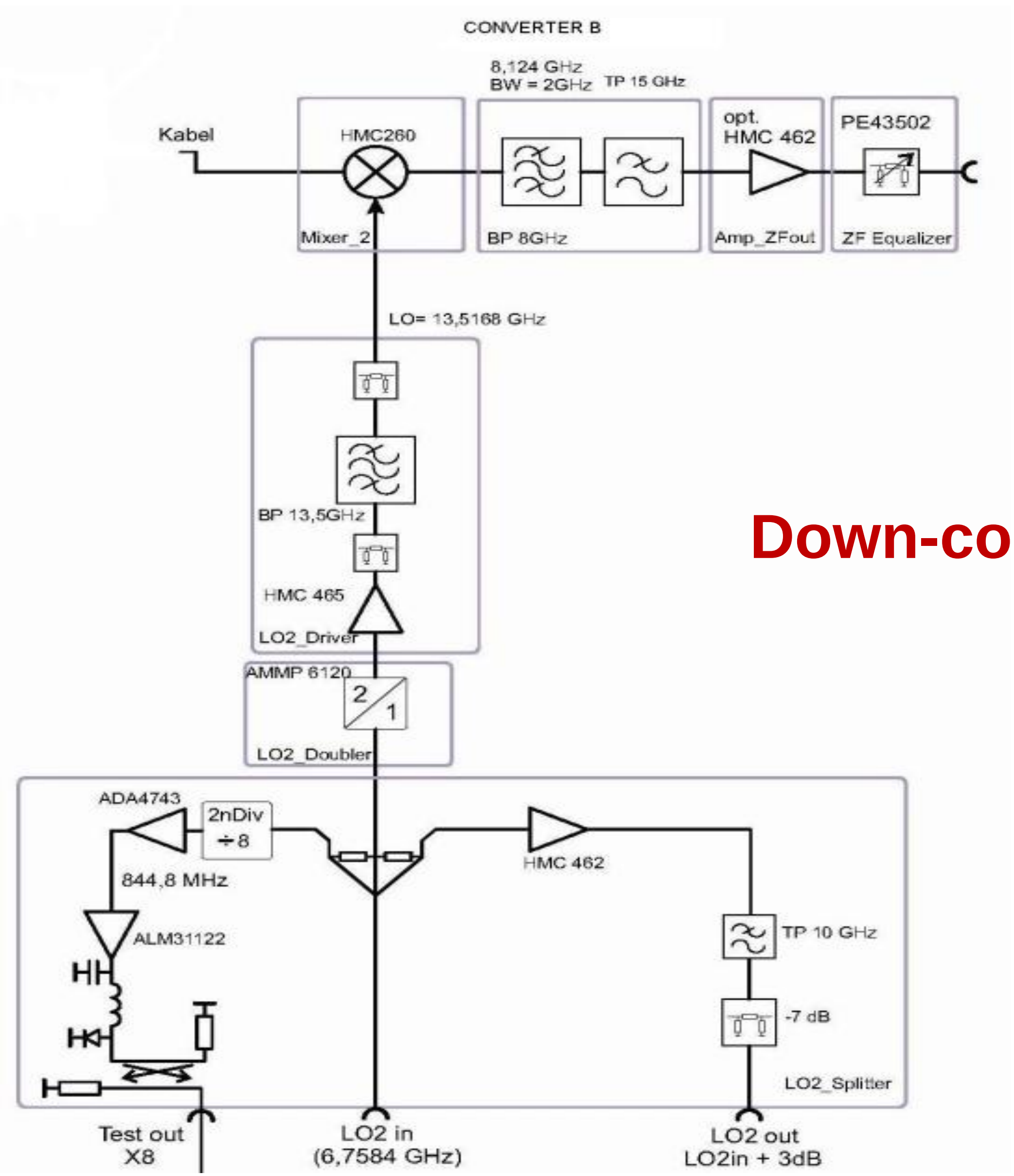


Typical Down-Conversion Architecture



Down-converter of the receiver

Typical Down-Conversion Architecture



Down-converter of the receiver

Antenna for Communication Receiver

Typical Antennas for high dynmaic range Communications Receivers

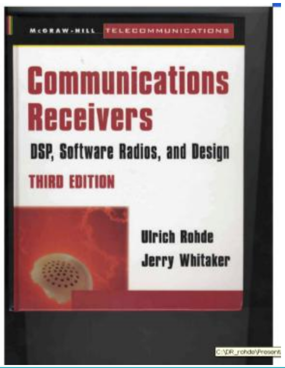
Input level up to 0 dBm !

Conclusion

- High Dynmaic Range Microwave Monitoring Receivers
- Software Defined Radio
- Analog Frond End: Pros & Cons
- Image Rejection Mixer: Eliminate triple conversion
- Important Characteristics of A/D converters
- Important Characteristics of Down Converters
- Characteristics of AGC
- Carrier recovery of Data Communication
- Spectrum Analysis of Communication Receiver
- Typical Architecture of Communication Receiver

References


Ulrich L. Rohde "radio house"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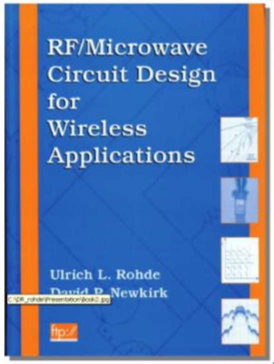
Jerry Whitaker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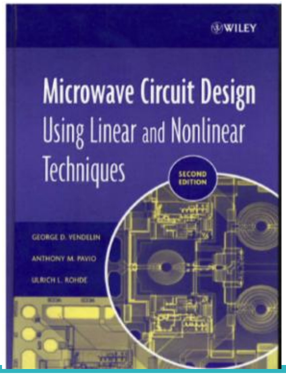
Ulrich L. Rohde
David P. Newkirk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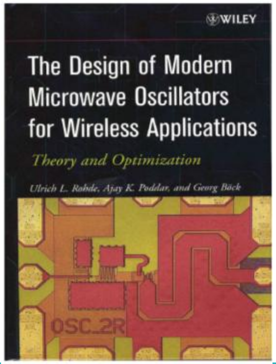
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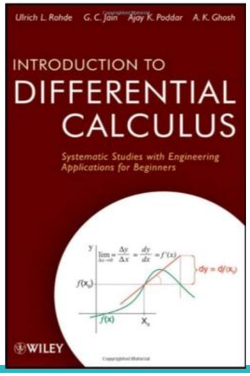
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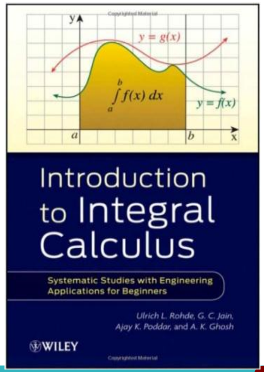
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Thank You