WILL THERE BE THE ALL DIGITAL RADIO IN THE FUTURE?

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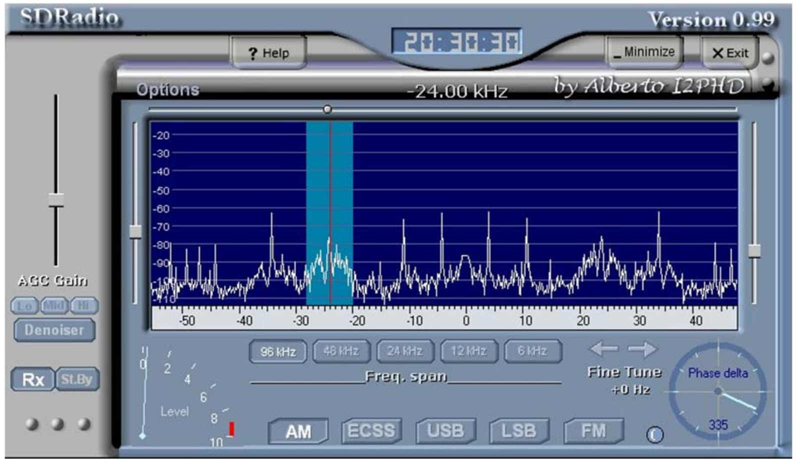

http://www.b-kainka.de/bastel114.htm

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Motivation for an "All Digital Radio"
Dr. Mitola more than 20 years ago

The ideal software radio **interoperates with any communications service** in its RF preselector band and A/D bandwidth. […], the software radio **instantly reconfigures itself** to the appropriate signal format. […] A future software radio might **autonomously select the best transmission mode** ([…]), send probing signals to establish a link, explore communications protocols with the remote end and **adapt to the remote signal format**.

It could select the mode for **lowest cost**, **service availability** or **best signal quality**.

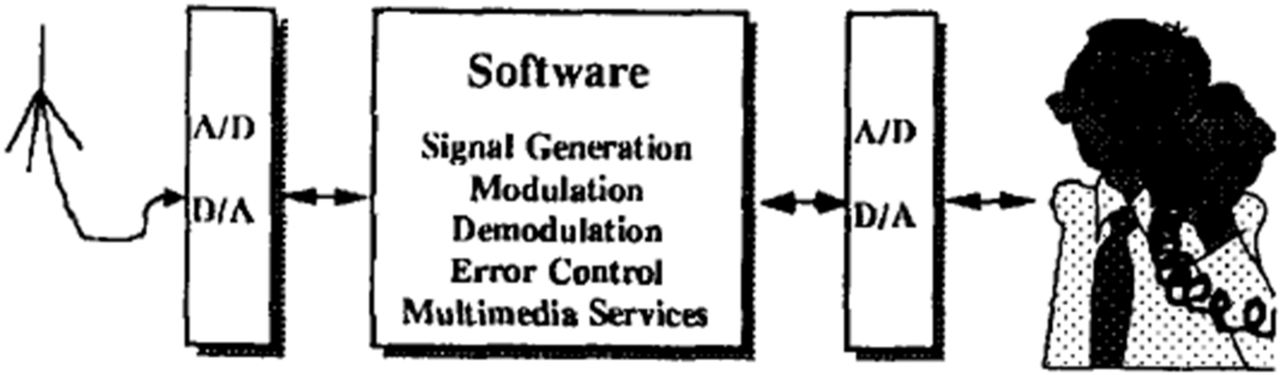
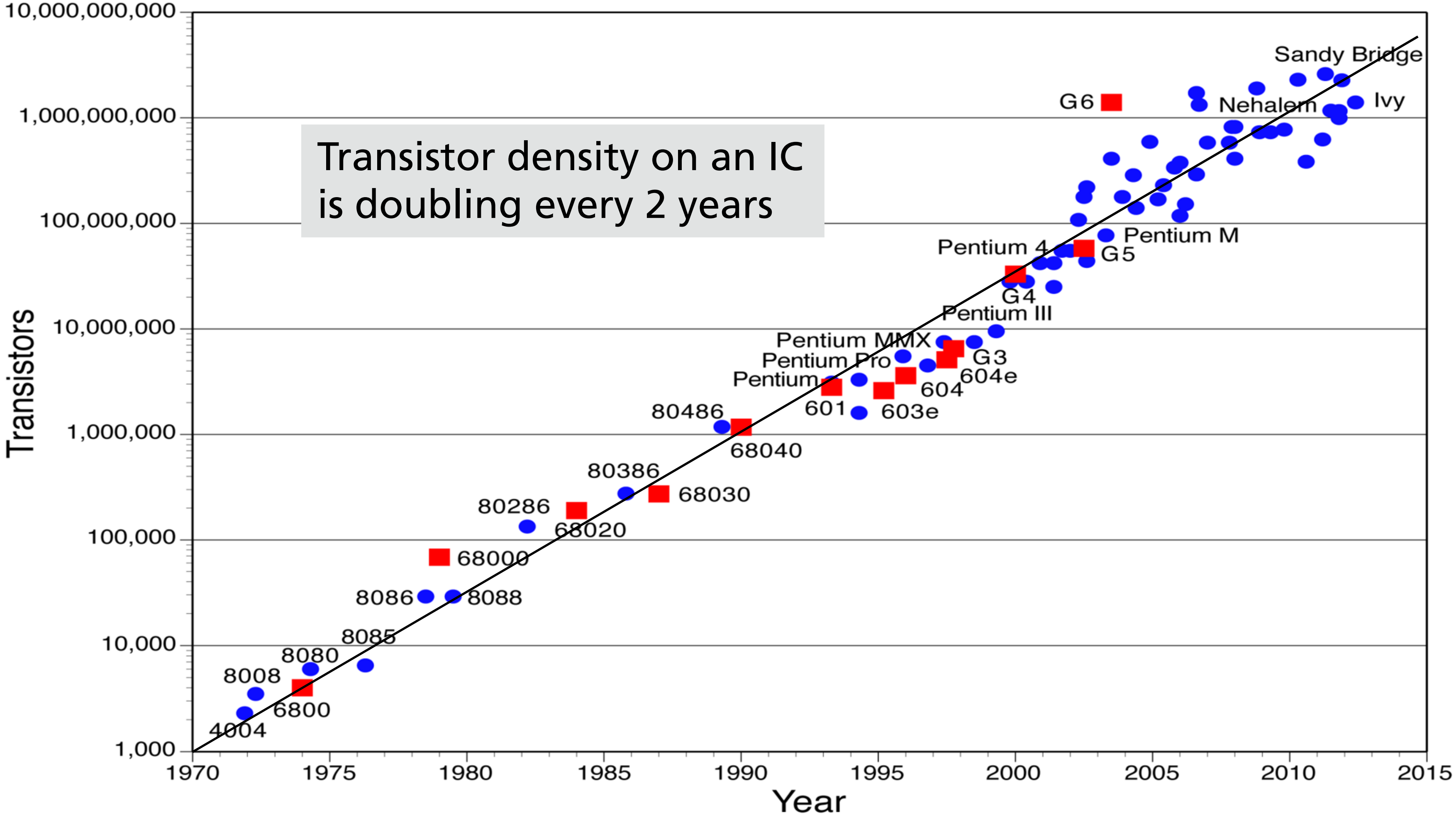


Fig. 1. An Idealized Software Radio

J. Mitola, Software Radios Survey, Critical Evaluation and Future Directions, 1993

Motivation for an "All Digital Radio"

Moore's Law for digital signal processing



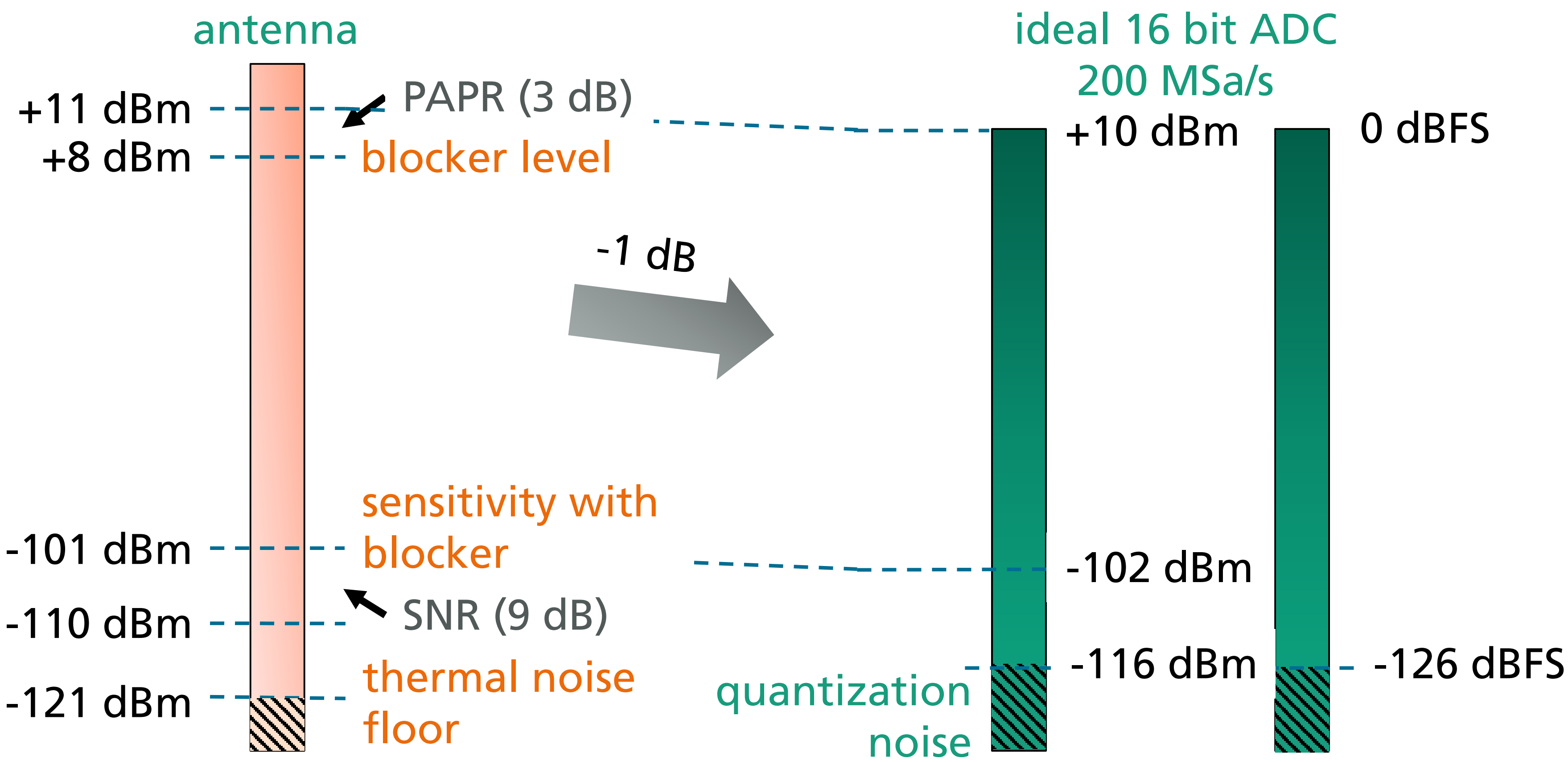
http://education.mrsec.wisc.edu/SlideShow/images/computer/Moores_Law.png

WILL THERE BE THE ALL DIGITAL RADIO IN THE FUTURE?

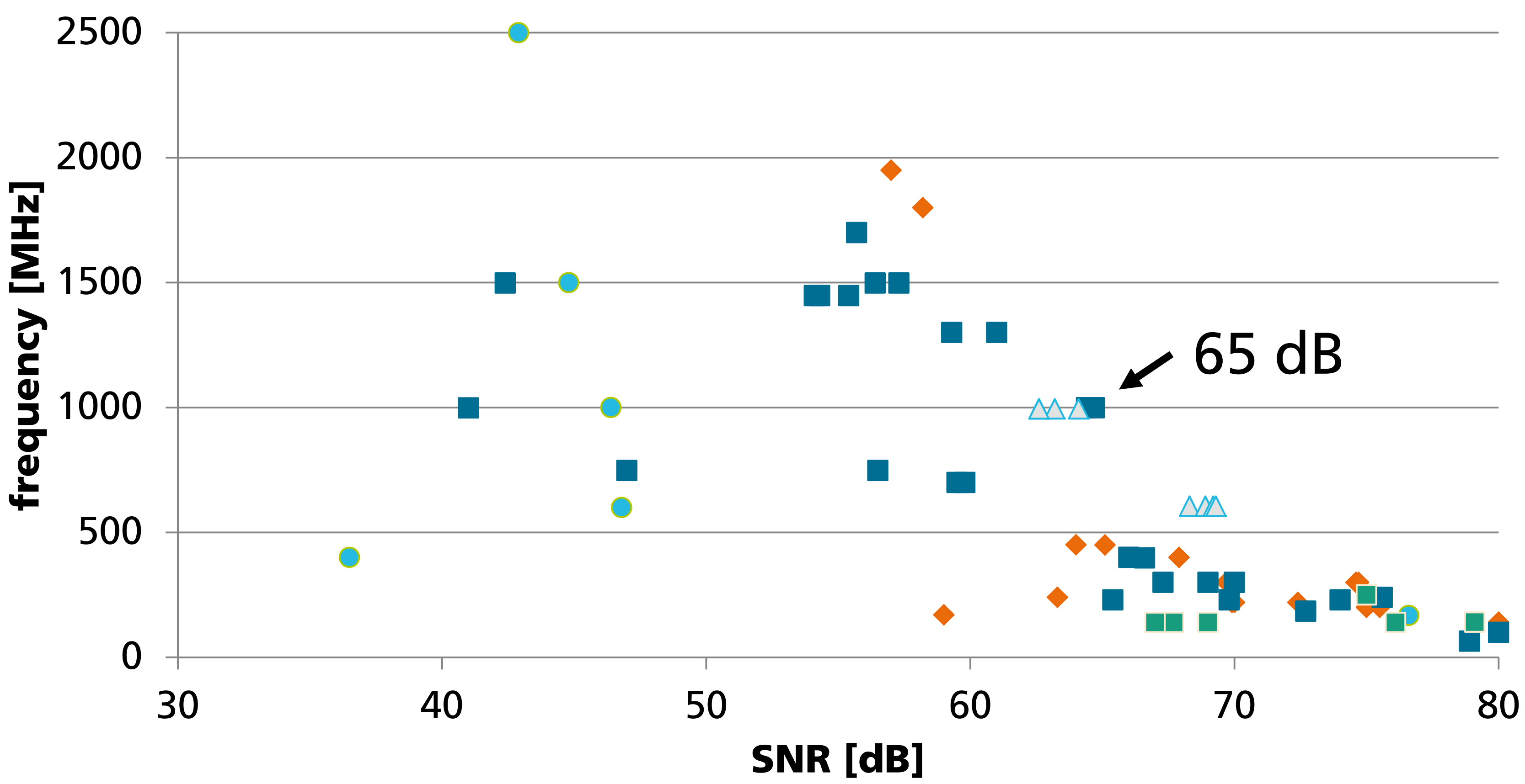
- Motivation for an “All Digital Radio”
- Limitations of the “All Digital Radio”
  - Dynamic range requirements
  - Performance of key components
- Dynamic range enhancement technologies
- Have a look into the future …
  - Beyond analog versus digital
  - Examples
- Conclusion

Requirements on a direct sampling RX frontend

Example: GSM BTS Out-of-band blocking requirement



Performance of state-of-the-art high-speed ADCs
SNR at max. measured frequency (from datasheet)



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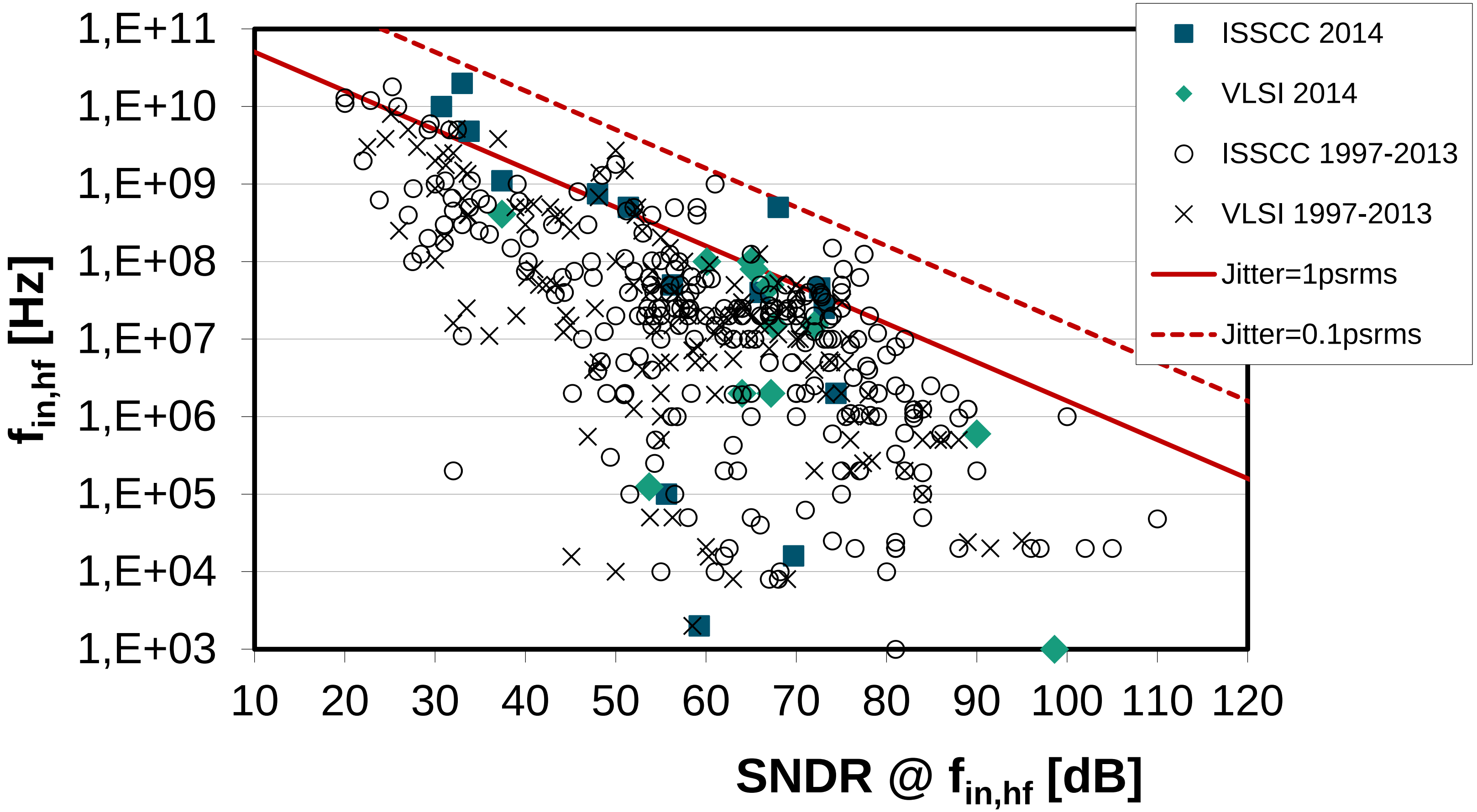
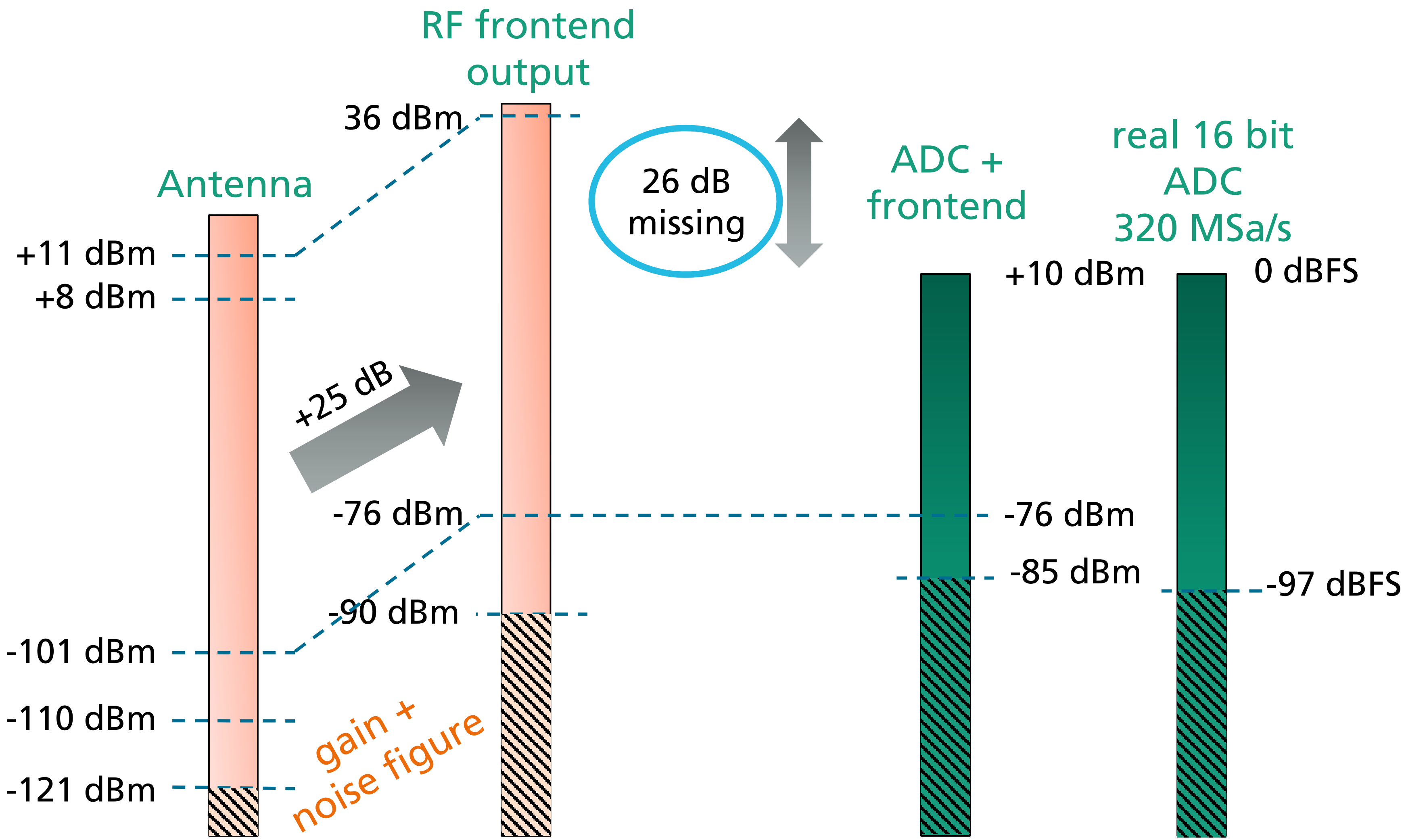
ADC performance
Published data from ISSCC and VLSI conferences



aus B. Murmann, "ADC Performance Survey 1997-2014," [Online].
available: http://www.stanford.edu/~murmann/adcsurvey.html.

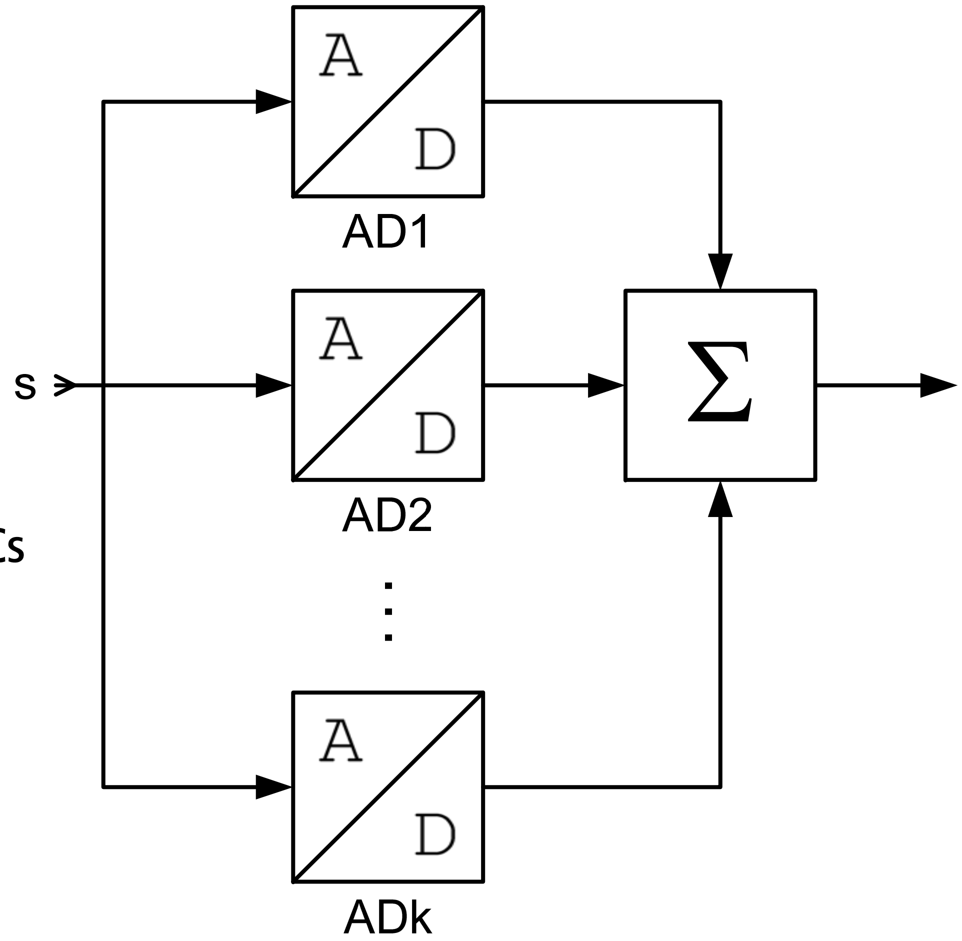
Requirements on a direct sampling RX frontend
Example: GSM BTS Out-of-band blocking requirement



Enhancement of ADC dynamic range
Signal averaging with parallel ADCs

Idea:

- Signal sums coherently
  2 ADCs => 6 dB more level
- Noise is uncorrelated and sums on an RMS basis
  2 ADCs => 3 dB more Noise
- Gain of 3 dB in SNR with every doubling of the number of ADCs
- High demands on phase and amplitude errors



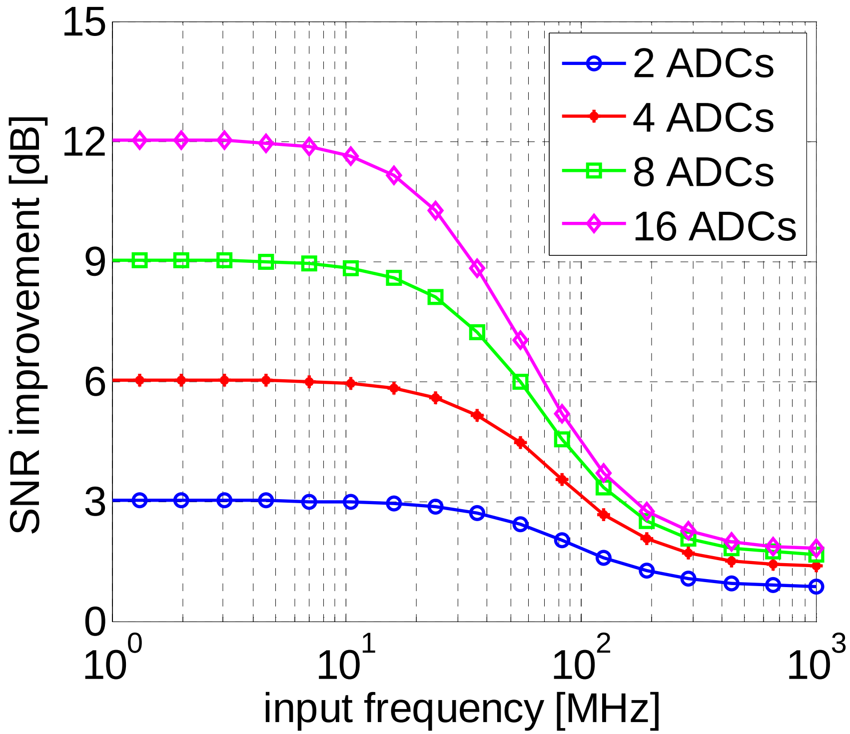
Enhancement of ADC dynamic range
Signal averaging with parallel ADCs

- According to Lauritzen: $$\mathrm{SNR} = \left(\frac{1}{k \cdot \mathrm{SNR}_{therm}} + \frac{(\omega \cdot \sigma_m)^2}{k} + (\omega \cdot \sigma_\mu)^2 \right)^{-1}$$

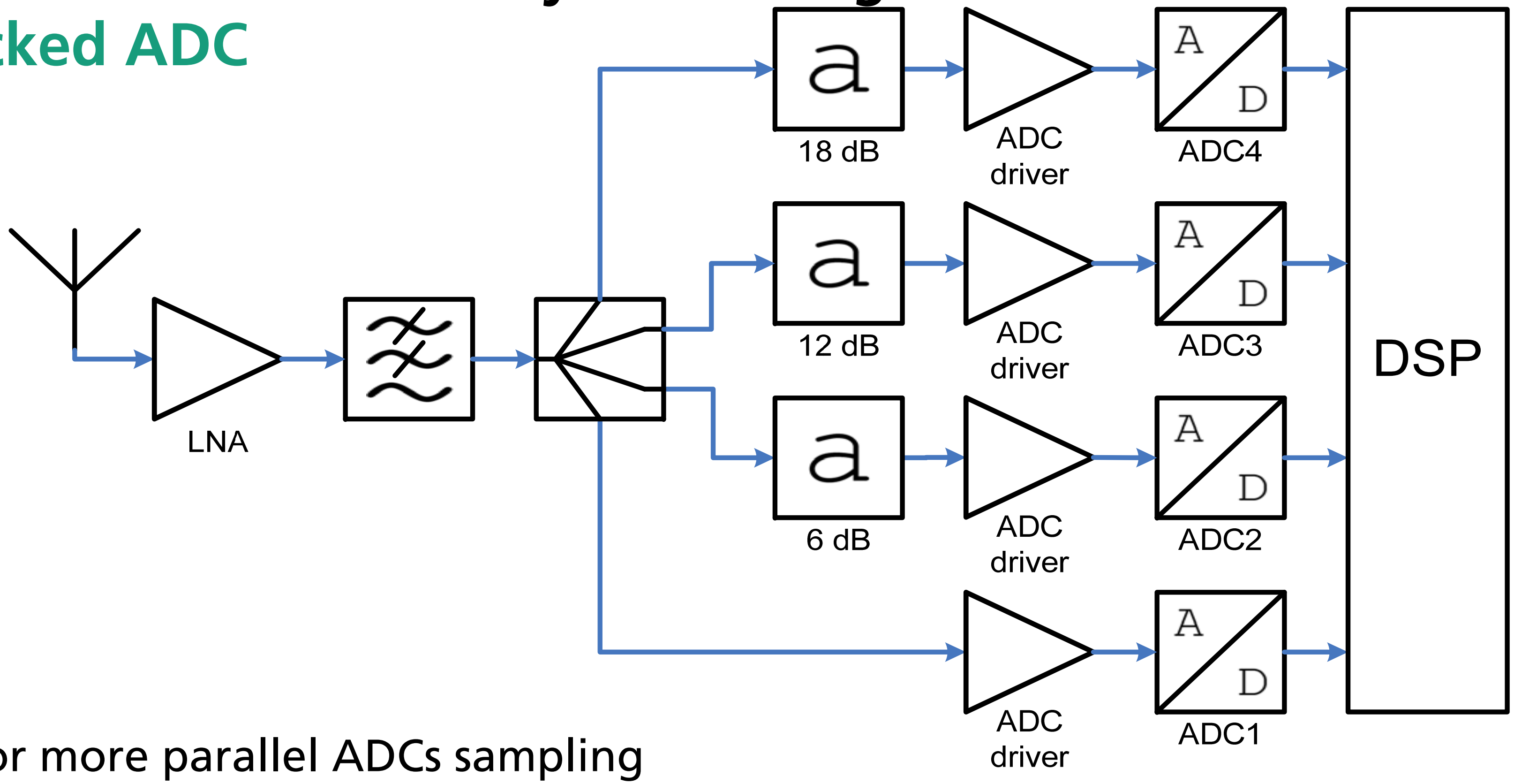
  σ_m = aperture jitter and
  σ_μ = clock jitter

- Clock jitter is correlated and limits the improvement with higher input frequency

- Example:
  aperture jitter = 75 fs
  clock jitter = 100 fs
  SNR of the single ADC = 82 dB



Enhancement of ADC dynamic range
Stacked ADC

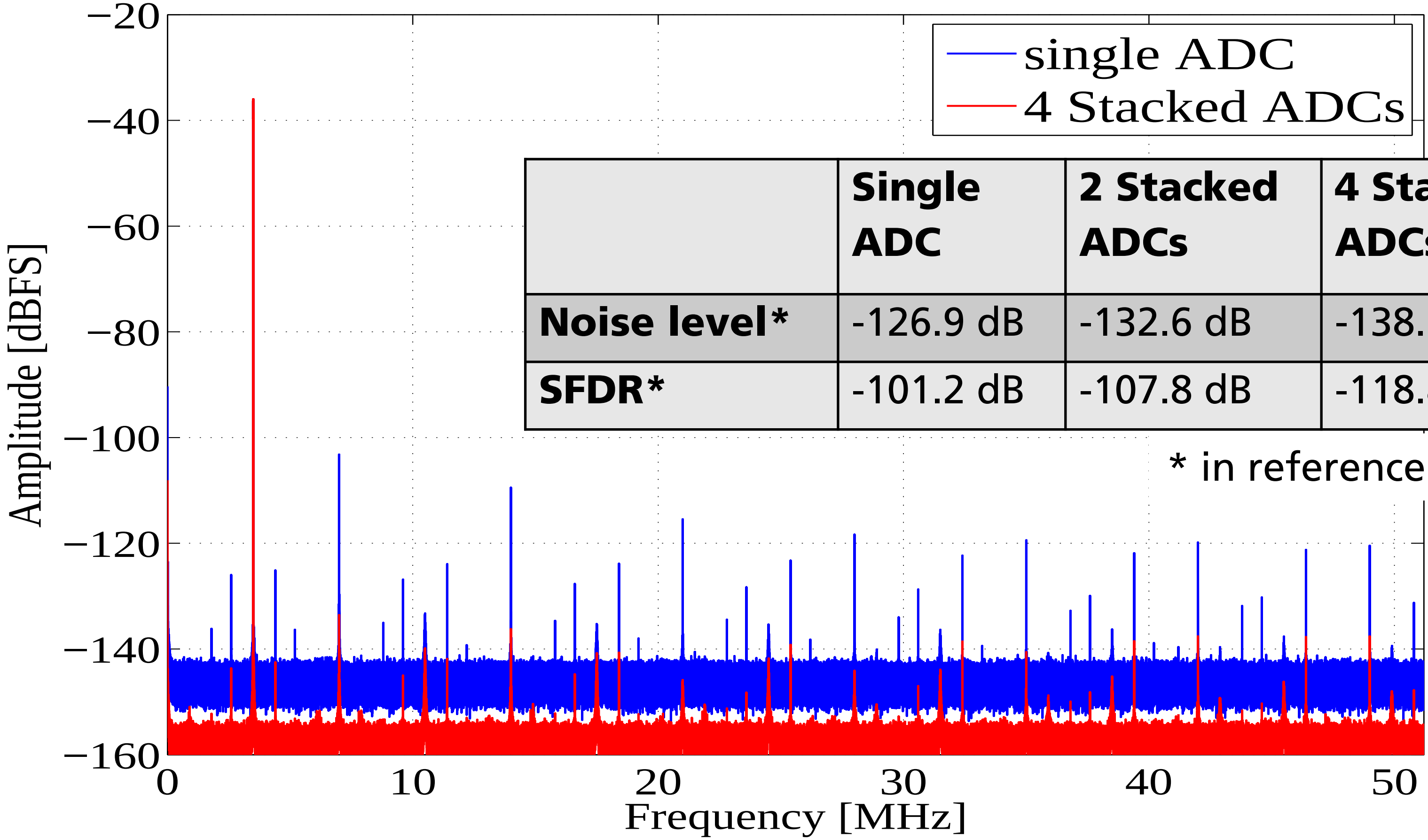


- 2 or more parallel ADCs sampling simultaneously the input signal with the same clock
- Attenuators causing different drive level of the ADCs
- If one ADC is overloaded, the sample will be taken from the next, not saturating ADC => switching AGC on a sample by sample basis

Stacked ADCs

Simulation results with OFDM interferer (10 kHz wide, 12.7 dB PAPR)

Almost 6 dB SNR improvement with doubling of number of ADCs



	Single ADC	2 Stacked ADCs	4 Stacked ADCs
Noise level*	-126.9 dB	-132.6 dB	-138.2 dB
SFDR*	-101.2 dB	-107.8 dB	-118.8 dB

* in reference to PEP

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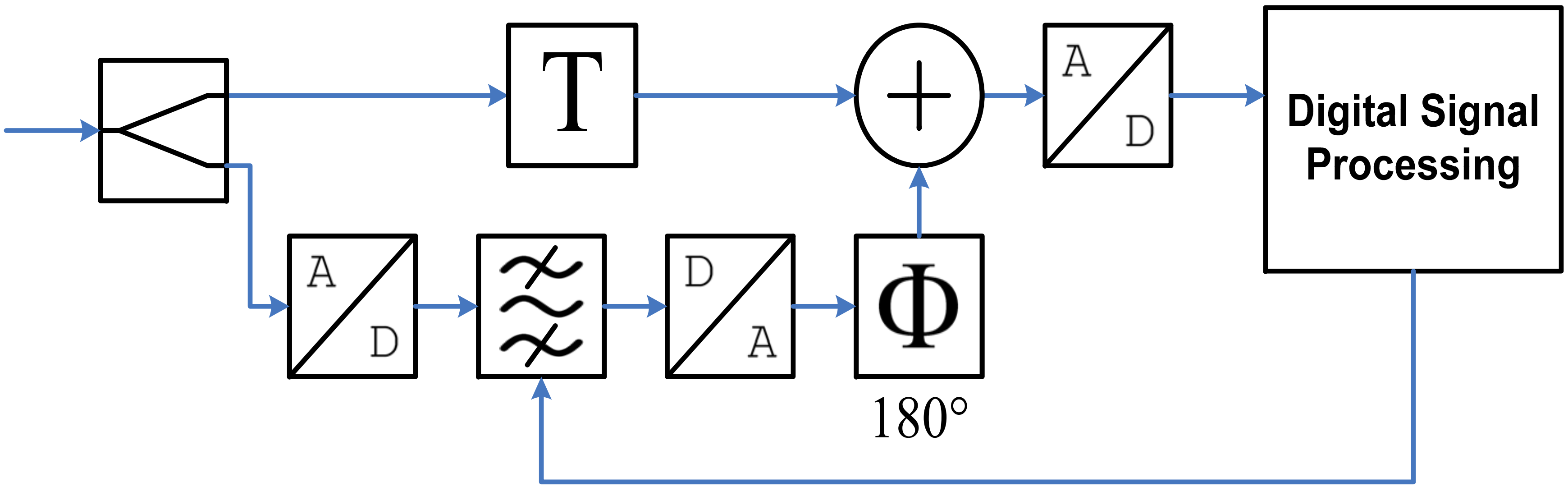
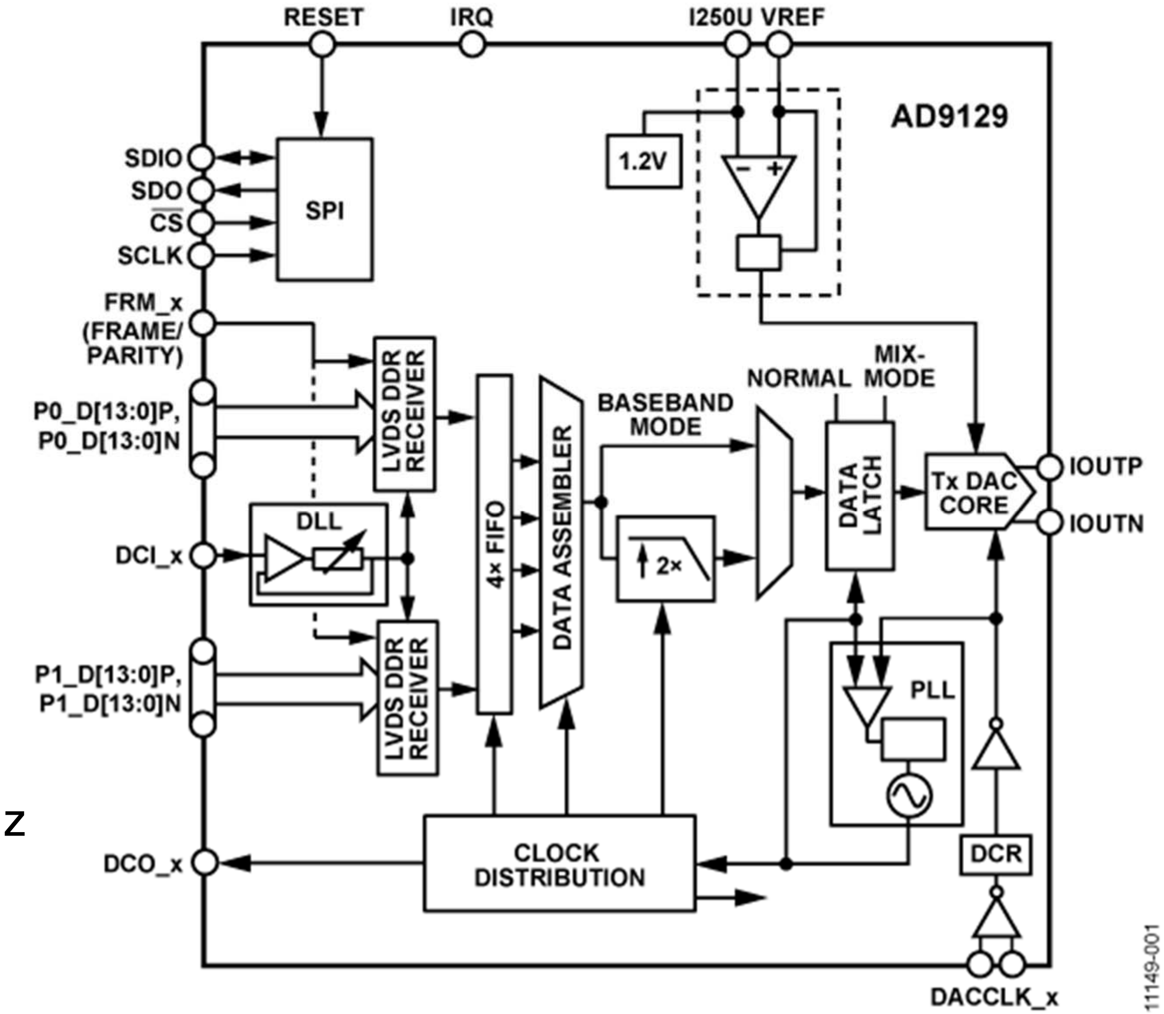
Reduction of interferer level
Feedforward interference cancellation

- Cancellation of Interferer before analog-to-digital conversion
- Most critical: adaptive filter and delay line
- Only a single interferer can be cancelled
- Details: Jing Yang, "Time Domain Interference Cancellation for Cognitive Radios and Future Wireless Systems"



DAC performance
Example: 14 bit at 5.7 GSa/s

- Frequency range:
  DC … 4.2 GHz
- Reasonable power consumption:
  1,3 W at full data rate
- SFDR @ 950 MHz:
  -55 dBc
- 2-tone IMD @ 950 MHz
  -76 dB
- Noise spectral density:
  -157 dBm/Hz @ 850 MHz



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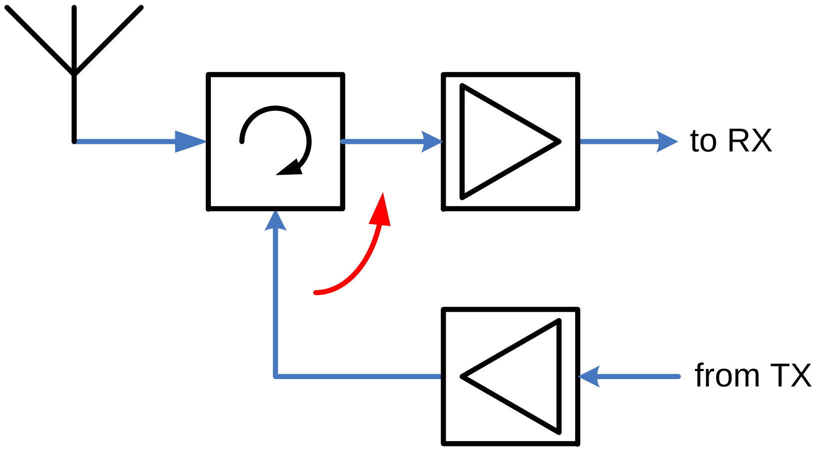
Transmitter dynamic range requirement
Whiteband noise

- DAC output power e.g. 10 mA in 100 Ω: 13 dBm
- GSM BTS with 20 W: 30 dB gain
- Wideband noise power: -127 dBm/Hz
  in 200 kHz: -73 dBm (noise figure of amplifier not considered)
  - For TDD applications: o.k.
  - For FDD applications or cosited RX:



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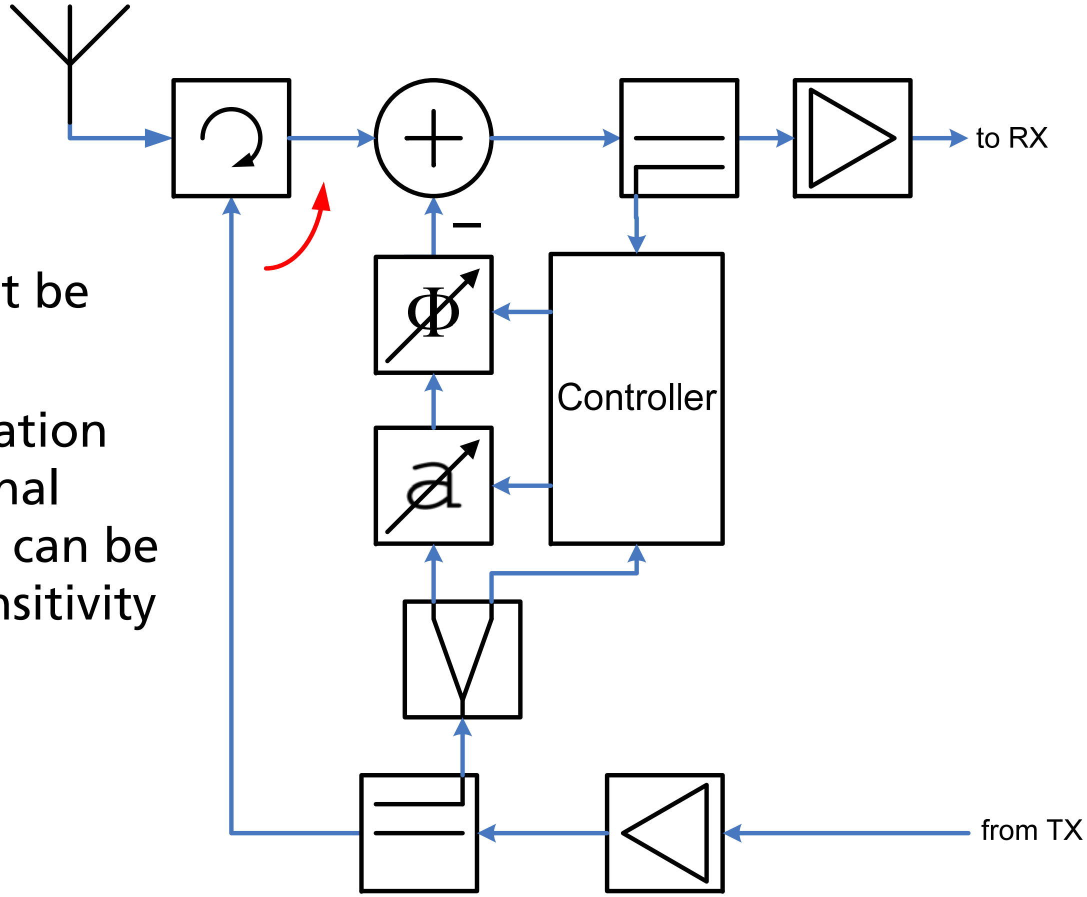
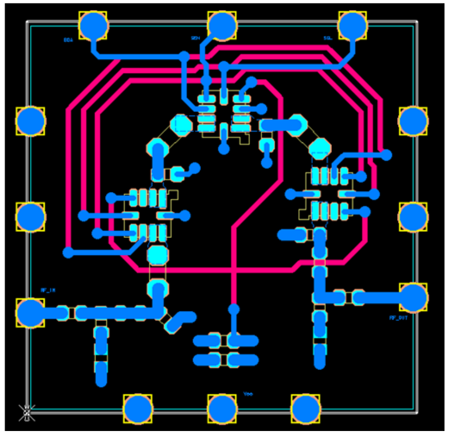
Reduction von TX noise in RX path
Noise and interference canceller

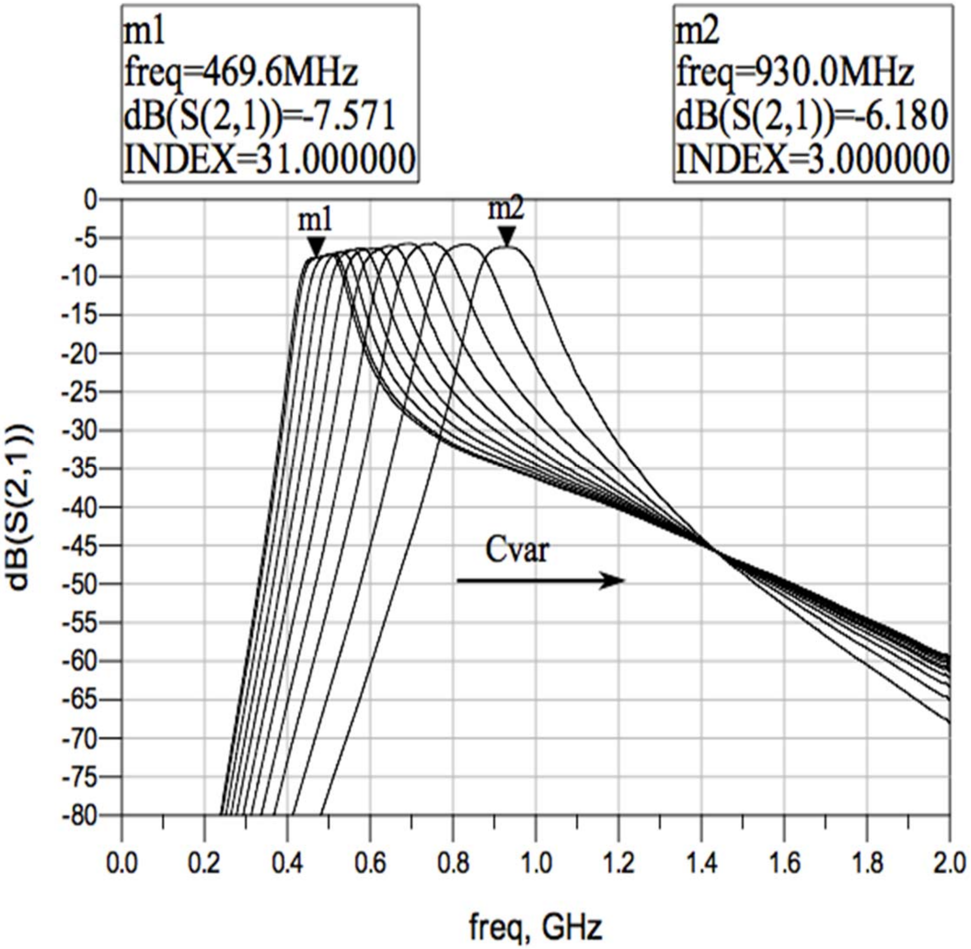
- In FDD, the own TX might be the strongest interferer.
- With a wideband cancellation loop, the transmitted signal AND the wideband noise can be reduced to gain some sensitivity at the receiver.



Reduction of interferer level
Reconfigurable filters

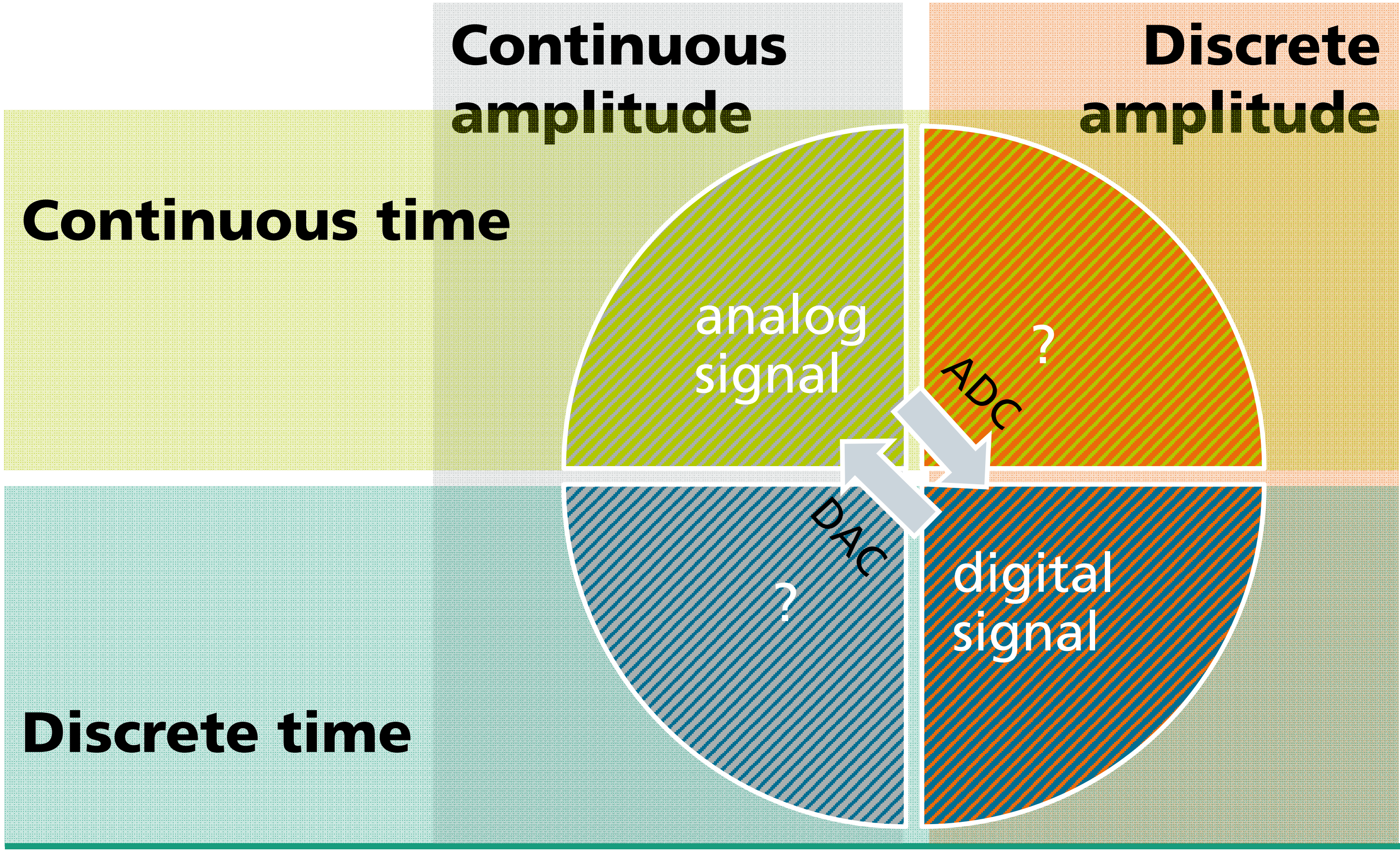
- 3 coupled resonators tuned by digitally tuned capacitors
- 3-wire SPI
- Tuning range 470 … 930 MHz
- Drop-in module
  20 mm x 20 mm



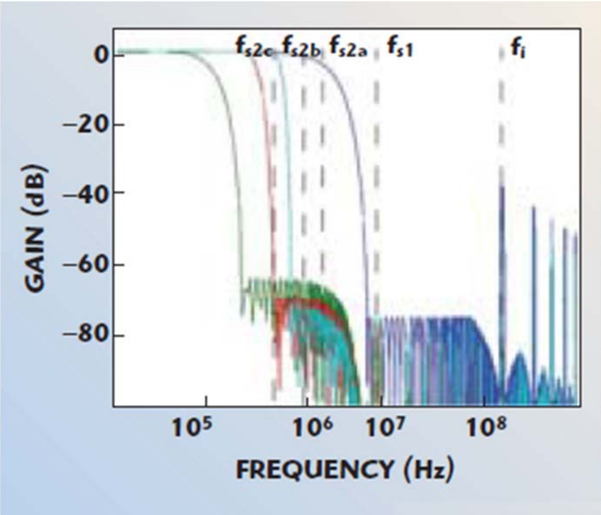


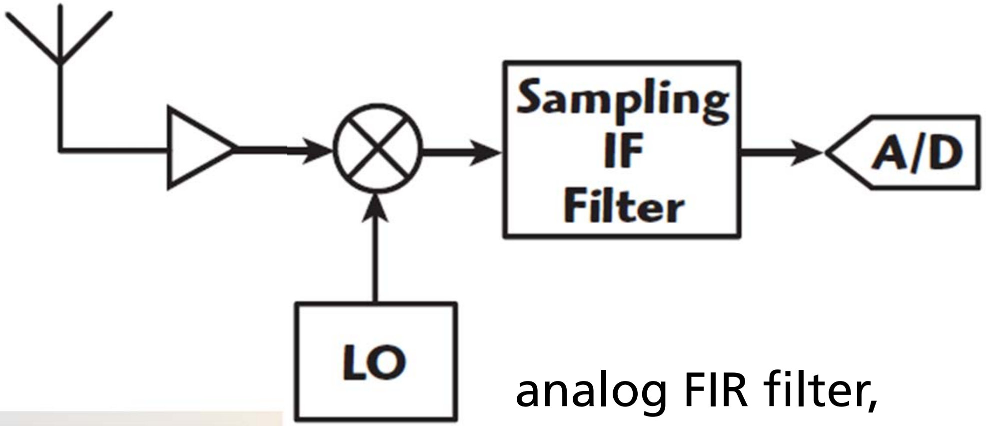
Do we need “digital” do benefit from Moore’s Law?

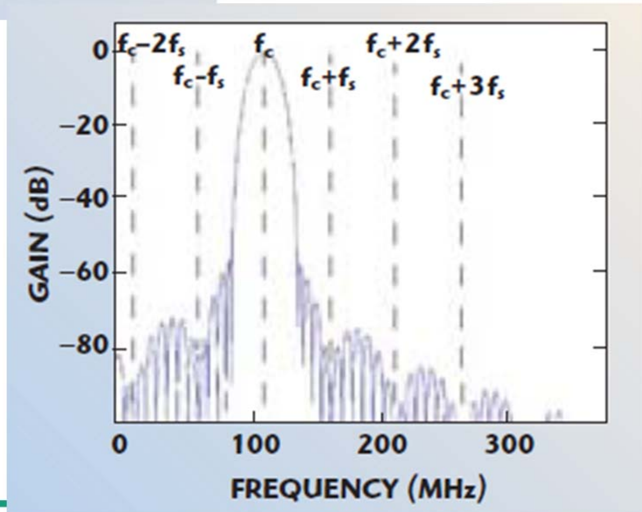
There might be more than just digital or analog …



Discrete time, continuous amplitude
Example: Sampling IF filter technology





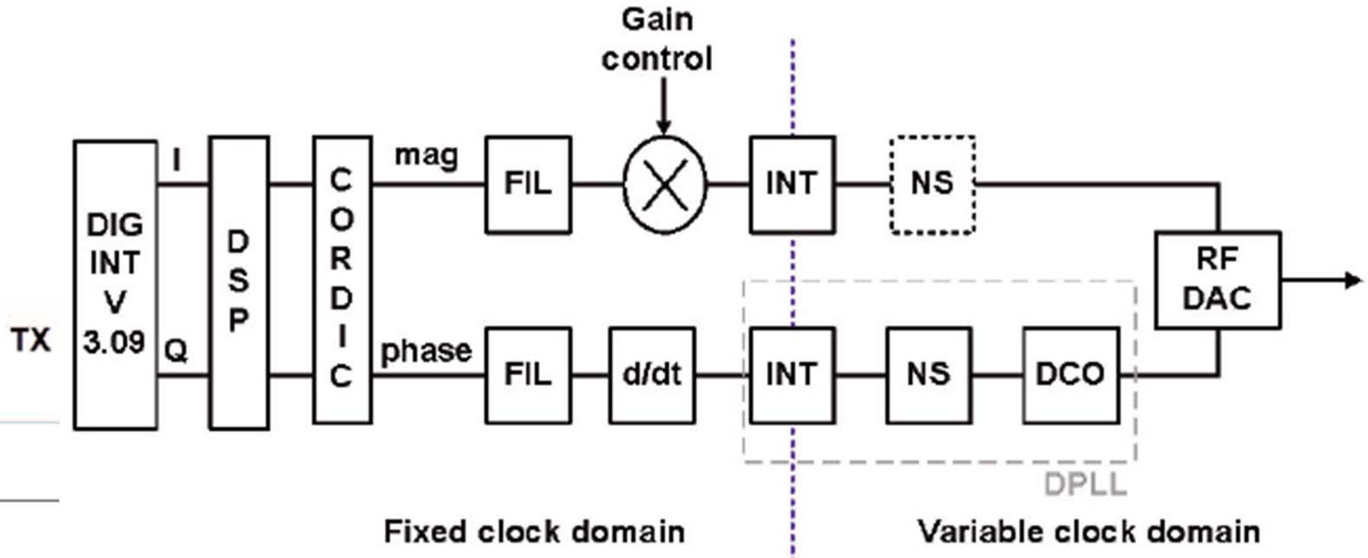


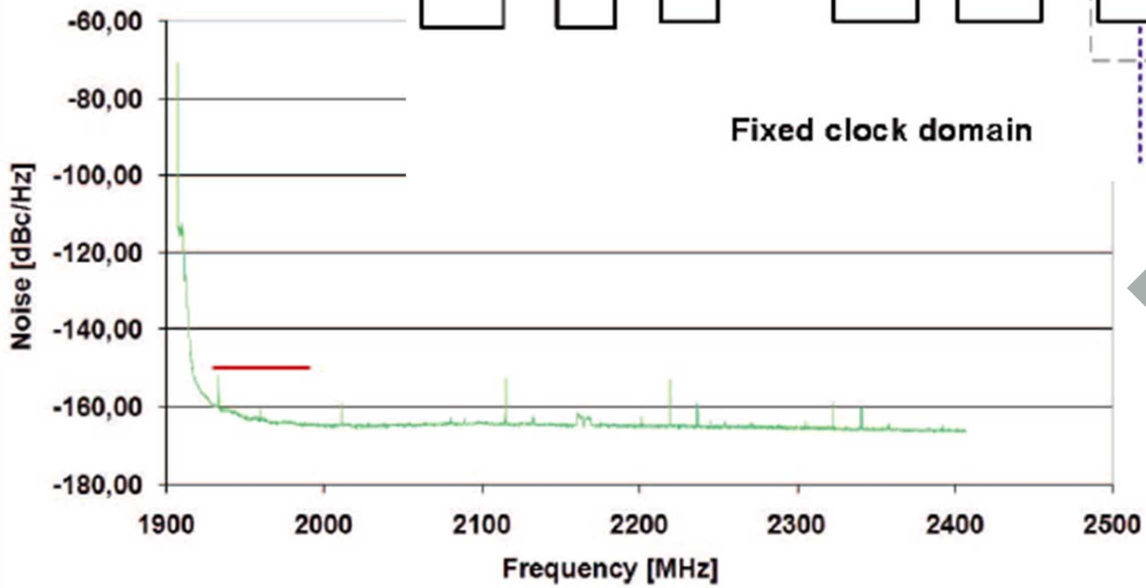
analog FIR filter,
up to 900 MHz

Seste Dell'Aera, Tom Riley, „Sampling IF filters and the return of the Superheterodyne Receiver", Microwave Journal 2005

Discrete amplitude, continuous time

Example: Fully Digital Multimode Polar Transmitter





EDGE TX spectrum
@ 1907 MHz

Zdravko Boos, et.al., „A Fully Digital Multimode Polar Transmitter Employing 17b RF DAC in 3G Mode", ISSCC 2011

CONCLUSION

- Digital HW getting still smaller, more power efficient, cheaper according to Moore’s Law => Fully Digital Radio is attractive
- A-to-D / D-to-A converters evolve, but still limiting the performance
- Fully Digital Radio can be a good solution for certain application in the future, but is not necessarily the best concerning price, power consumption and performance
- Fully Digital Radio will not be THE solution for all applications in the near future (e.g. FDD)
- There might be more than just analog or digital

Questions ?

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