# Adaptive Nonlinear Interference Suppression for Multimode Transceivers (DECAFE)

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Technische Universiteit
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University of Technology

**Where innovation starts**

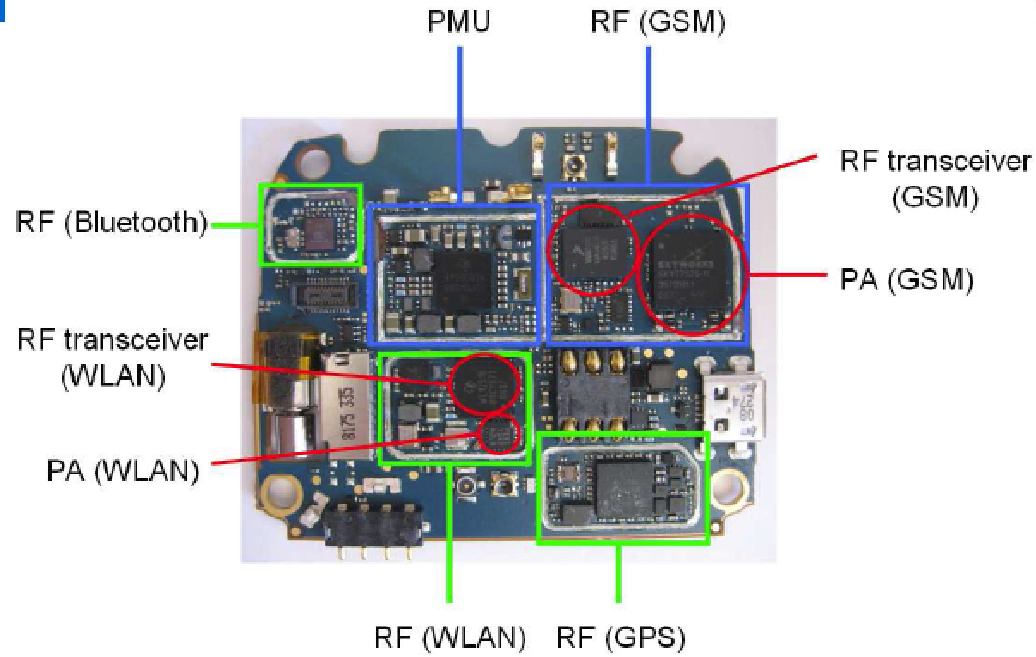
# DECAFE project

- **Funded by STW.**
- **Technical Support from CATENA and NXP.**
- **Cooperation between UT and TU/e**
- **Ph.D candidates involved in this presentation:**
  - **Hooman Habibi : TU/e, SPS group,**
  - **Erwin Janssen : TU/e, MSM group,**

# Outline

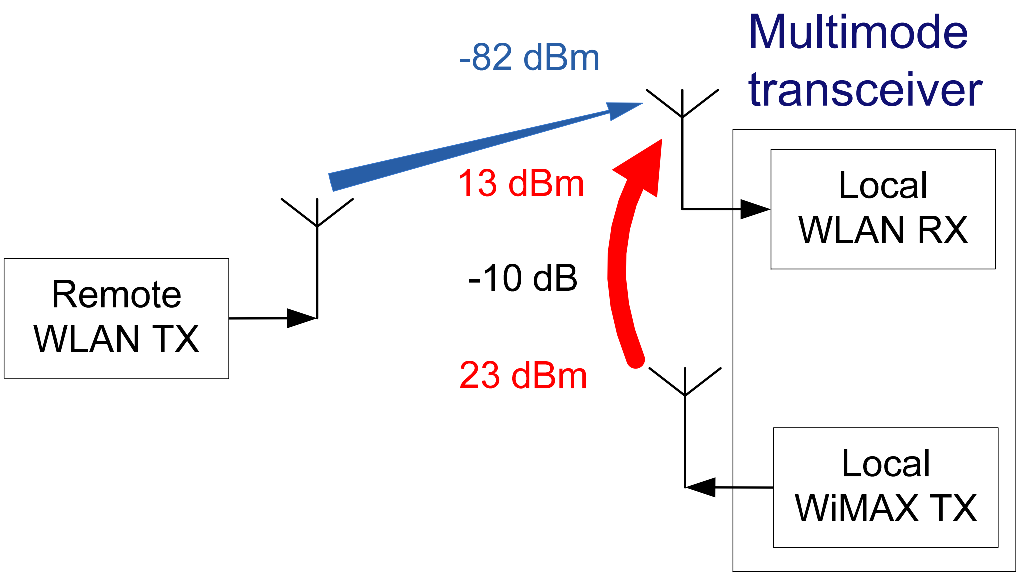
- Problem definition
  - Coexistence issues in multimode transceivers
- Proposed solution
  - Nonlinear Interference Suppressor (NIS)
  - NIS Adaptation
- Experimental results
- Concluding remarks

# Introduction: Multimode transceiver



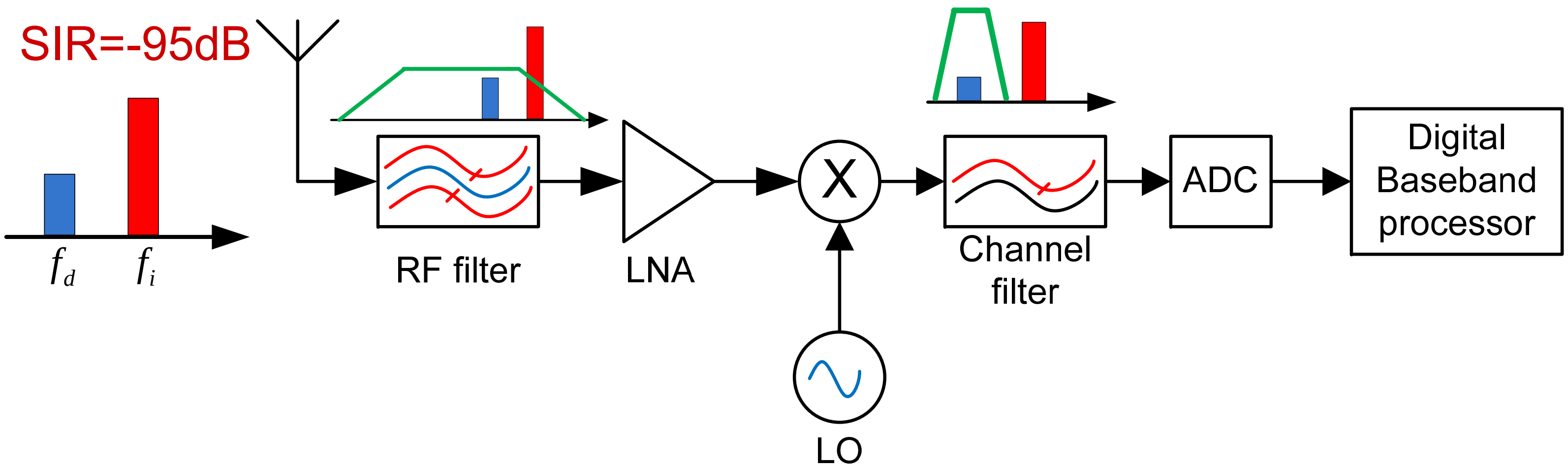

- **Multiple transceivers (may work simultaneously).**
- **Battery operated.**
- **Small size.**

# Local interference




- **An interferer much larger than the desired signal.**
  - **SIR at the WLAN RX : as low as -95 dB.**

# Interference in the receiver

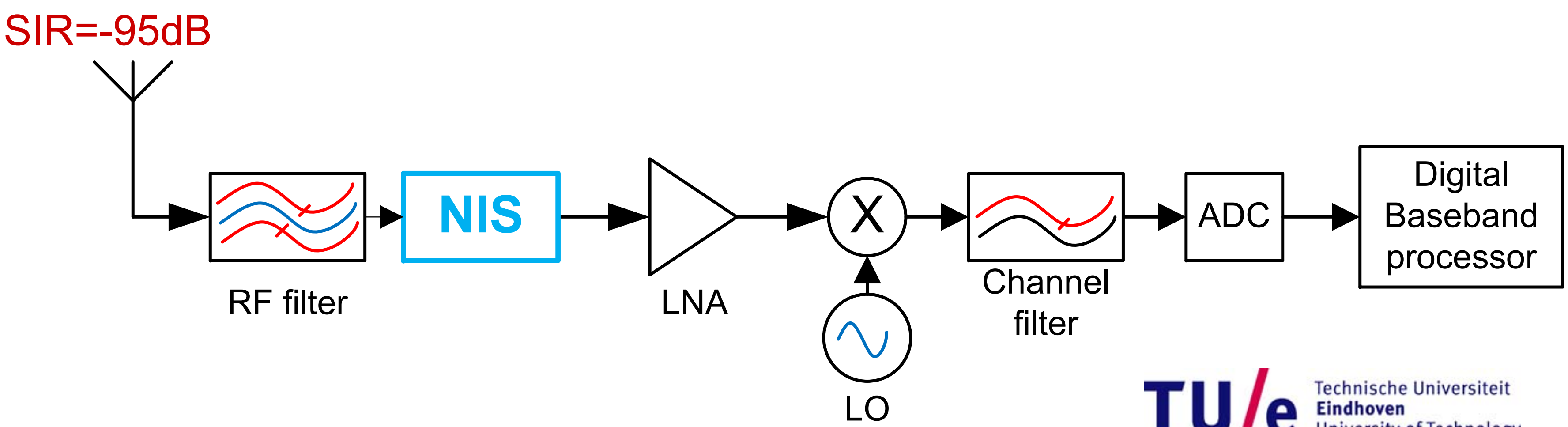



- **However the receiver front-end is not exactly linear.**

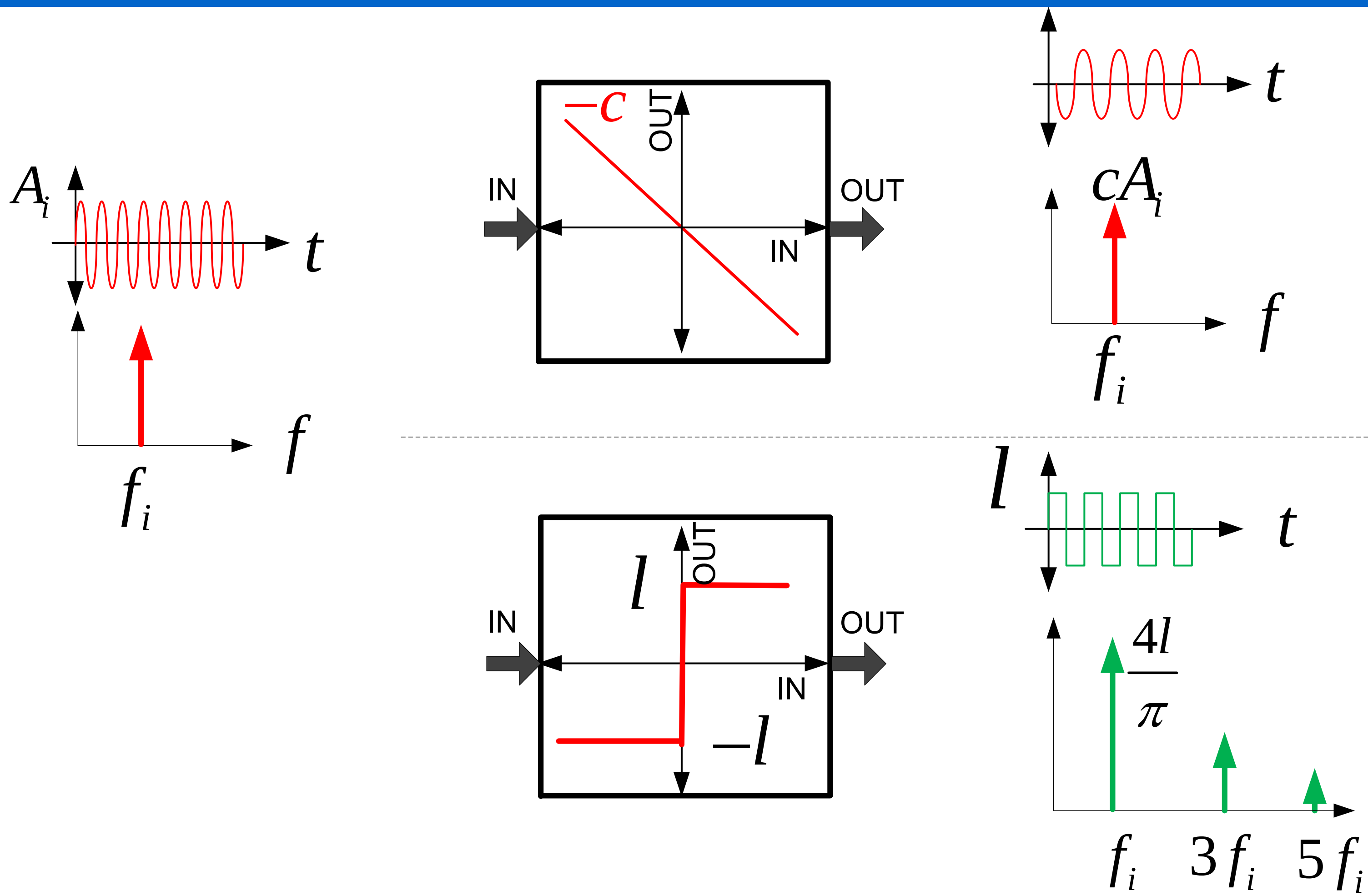

- **Gain loss=> Increased noise figure=> Desensitization.**
- **Increasing linearity=> increases pwr. Consumption.**

# Nonlinear interference Suppressor

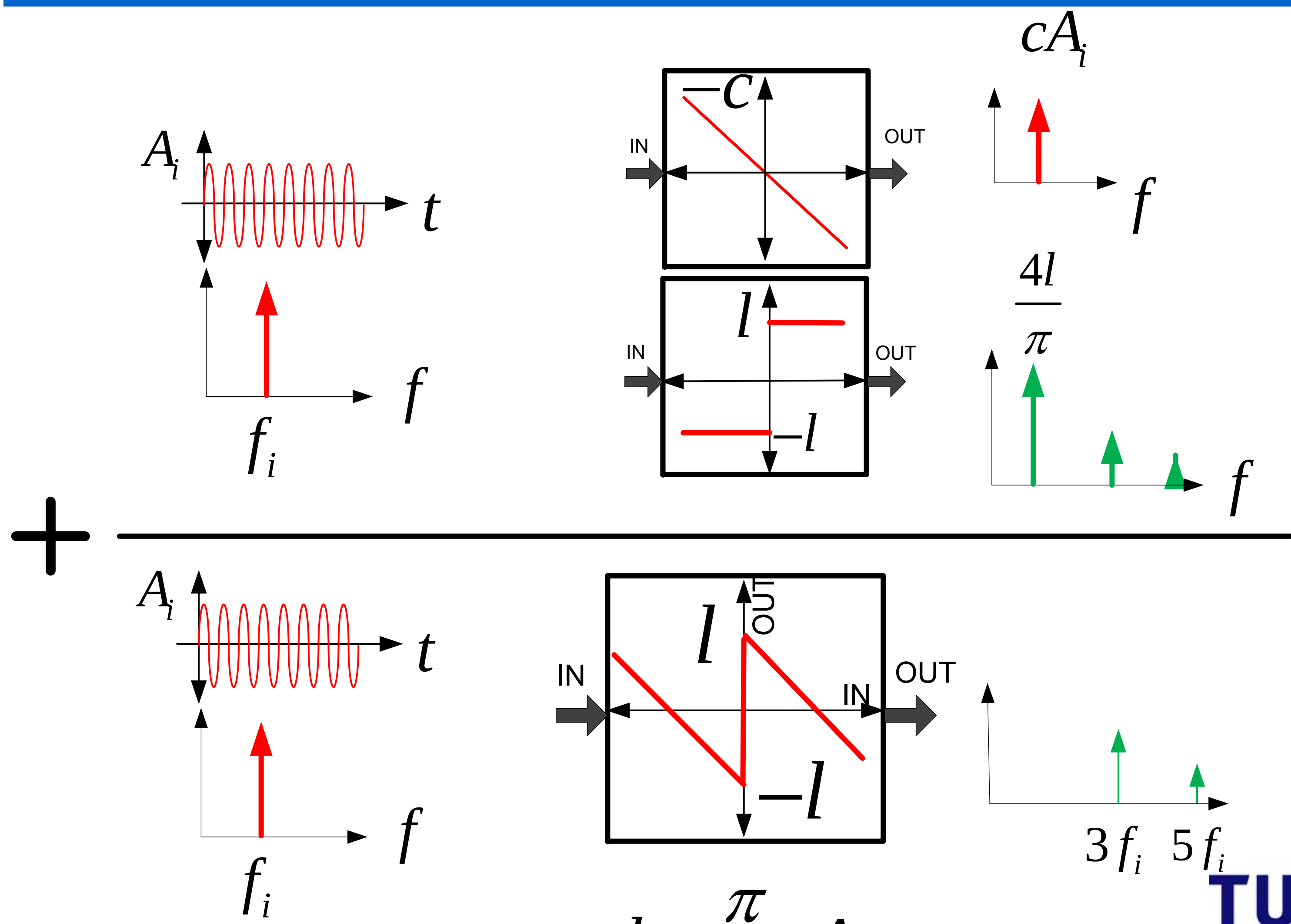
- **Suppression of the interference at an early stage.**
  - **The subsequent stages of the RX FE: Low power.**
- **Special adaptive nonlinearities can suppress a large signal while amplifying the weak desired signal.**



# Nonlinear interference Suppressor (NIS) Principle of operation #1:

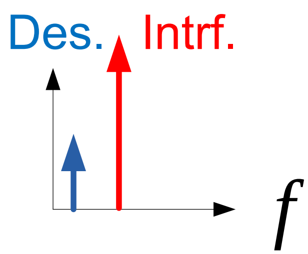


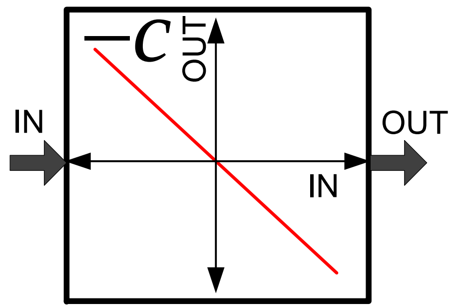
# NIS, Principle of operation #2:

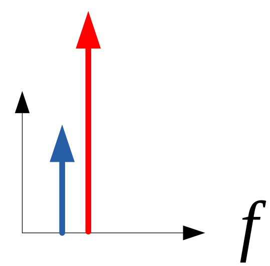



$$l = \frac{\pi}{4} cA_i$$

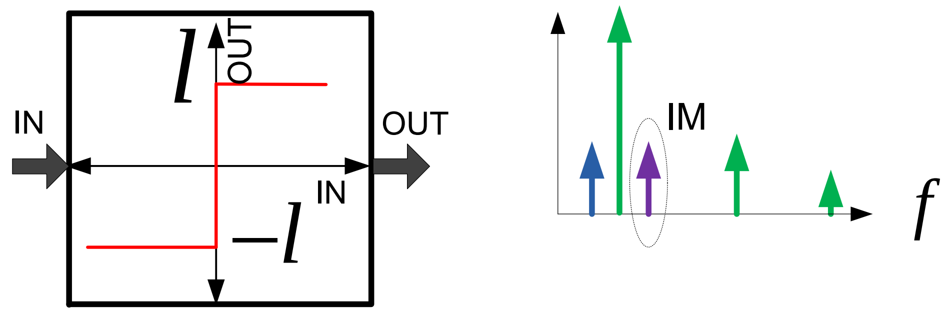
# NIS in the presence of the desired signal



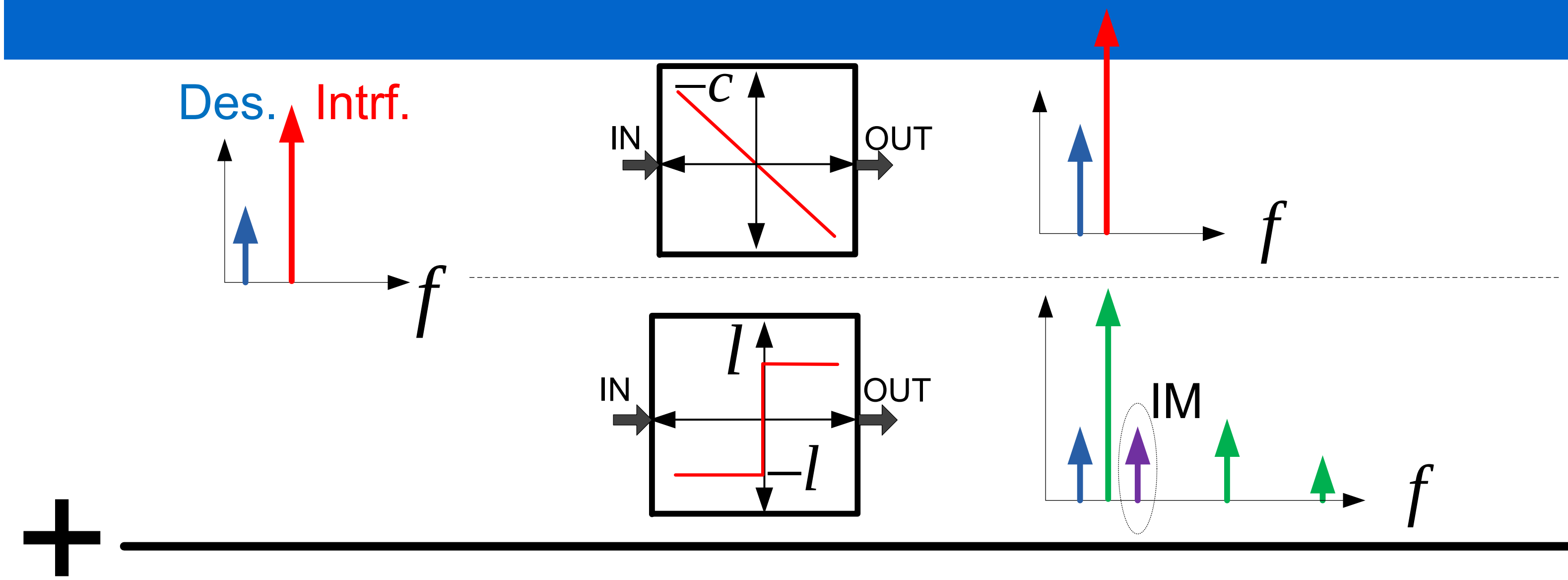

Intrf. G=-*c*
Des. G=-*c*

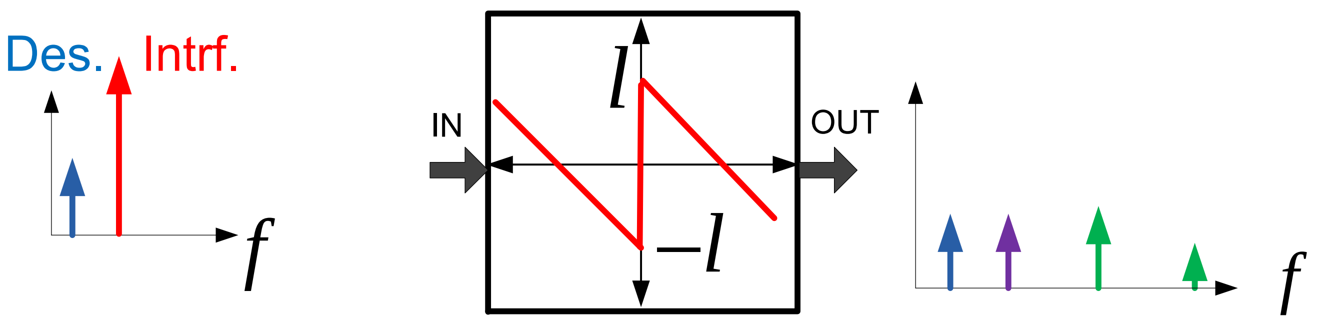



Intrf. G.=*c*
Des. G.=*c/2*

$$l = \frac{\pi}{4} c A_i$$

# NIS in the presence of the desired signal




Intrf. G.=*0*

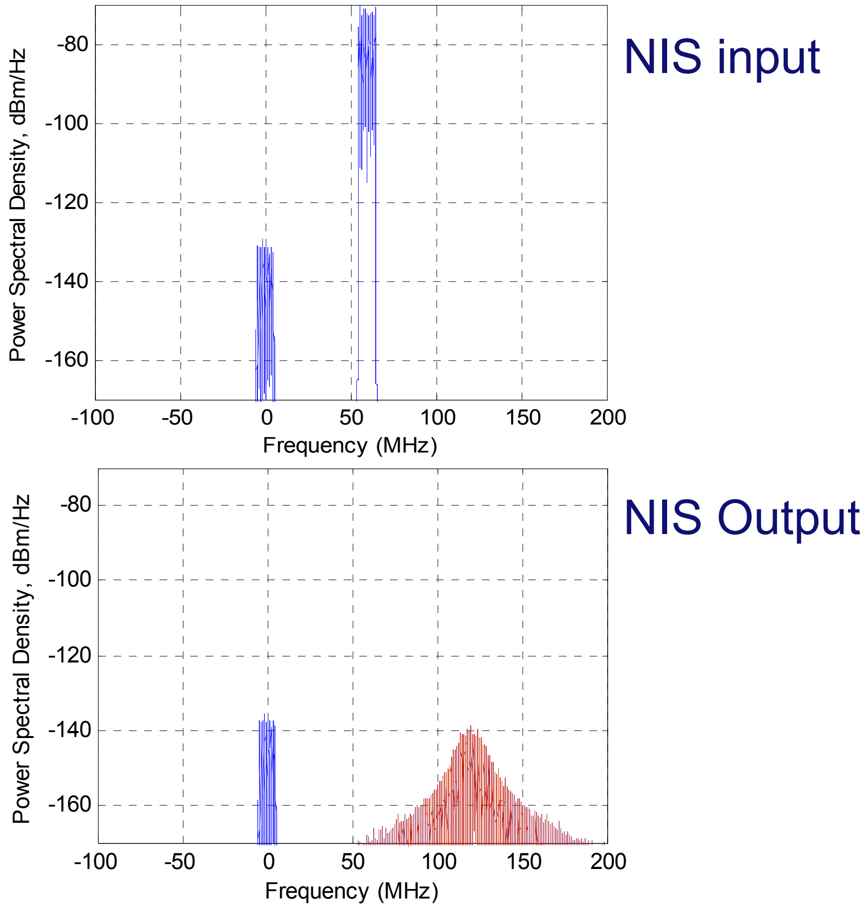
Des. G.=-*c/2*

$$l = \frac{\pi}{4} c A_i$$

# Modulated inputs, Intermodulation product

$$I(t) = \frac{\pi}{4} c A_i(t)$$

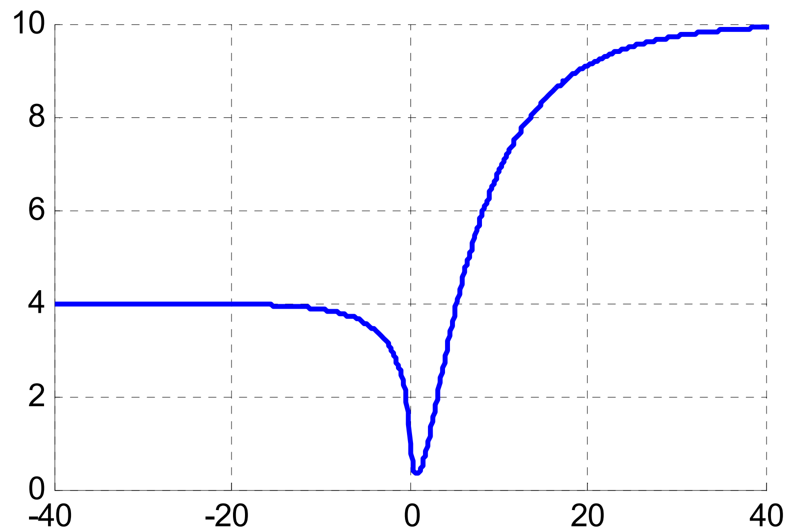
- Desired signal: OFDM 10 MHz BW
- Interfering signal : OFDM 10 MHz BW



# Modulated inputs,
# Gain Variation Distortion

- **The desired signal gain ($g_d$) is $c^2/4$ when $A_i >> A_d$**
- **The gain decreases when $A_i$ approaches $A_d$. dependence of gain to $A_i(t)/A_d(t)$ lead to nonlinear distortion**

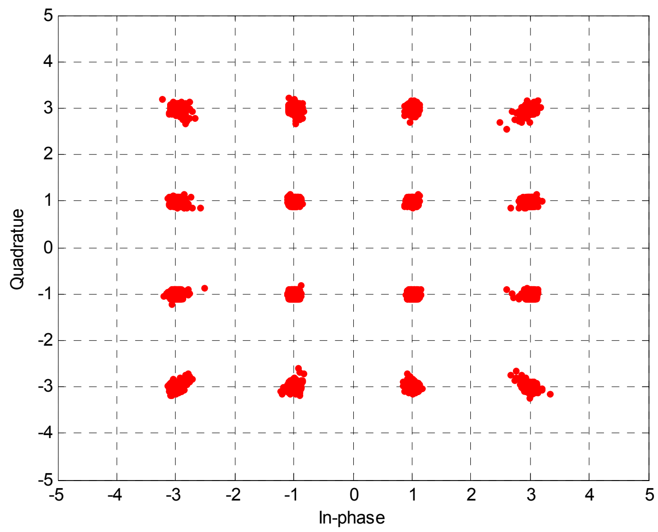
$g_d(t)$, dB



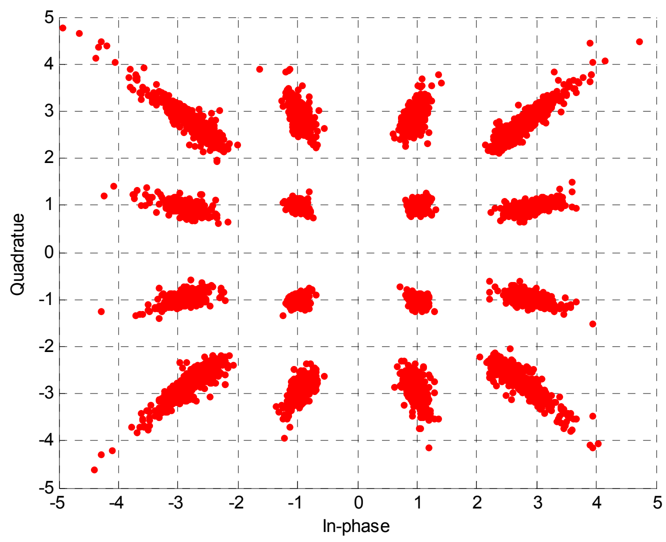

$$\left(\frac{A_d(t)}{A_i(t)}\right)^2, \text{ dB}$$

# Gain variation distortion, single carrier modulations

Both desired and interfering signals: Single carrier 16 QAM with raised cosine pulse shaping

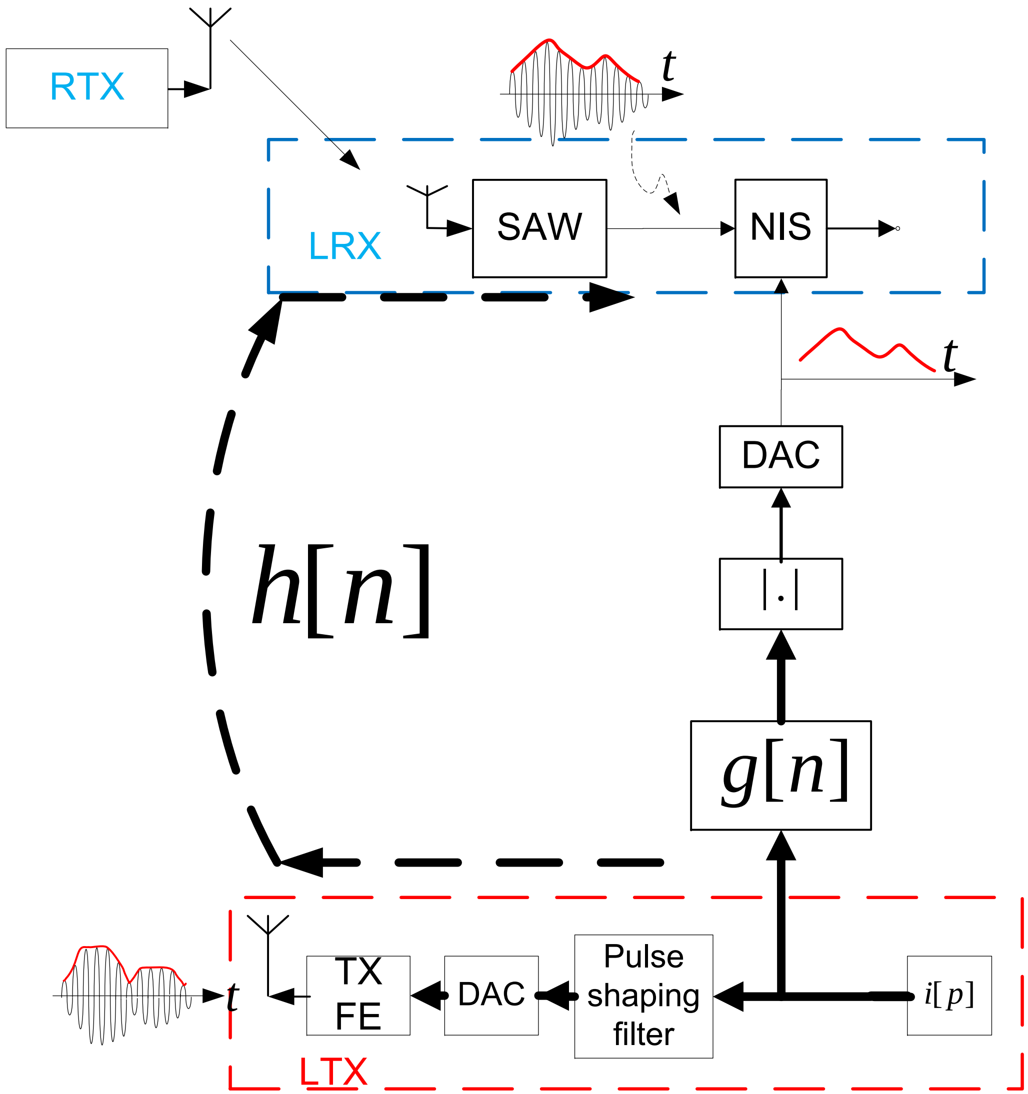



Input SIR : -30 dB




Input SIR : -10 dB

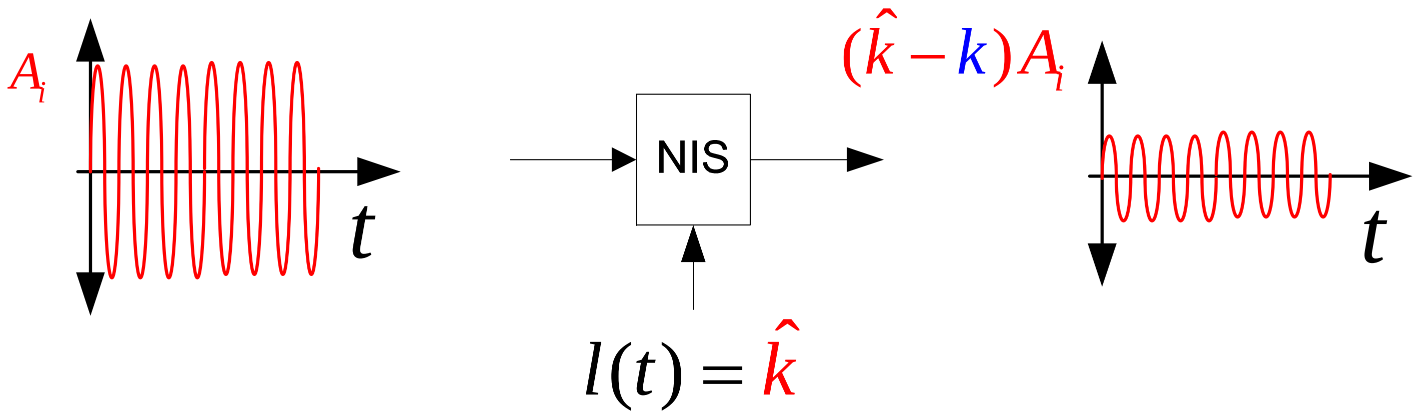
# NIS adaptation, (Feed-forward)




- Baseband signal of the transmitted interference is available locally.
- g[n] : FIR filter

# Accuracy requirement for adaptation signal

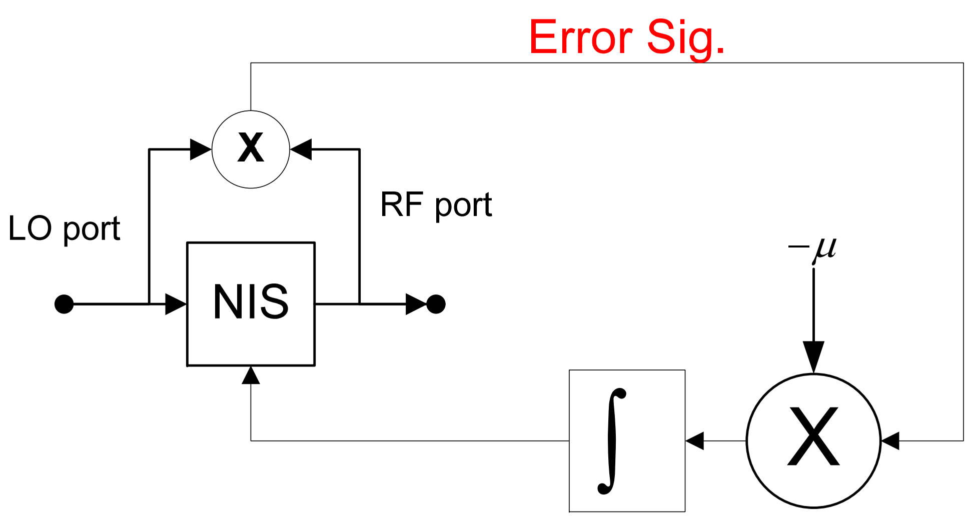
$l(t) = k$ nulls the interference at the NIS output

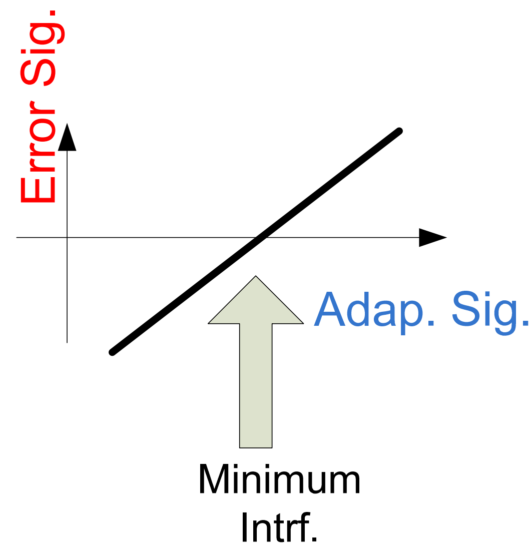



- **E.g. 40 dB suppression: Relative Adaptation Error< 0.5 %**
- **A closed-loop method is required to adapt the NIS based on residual interference at the NIS output.**

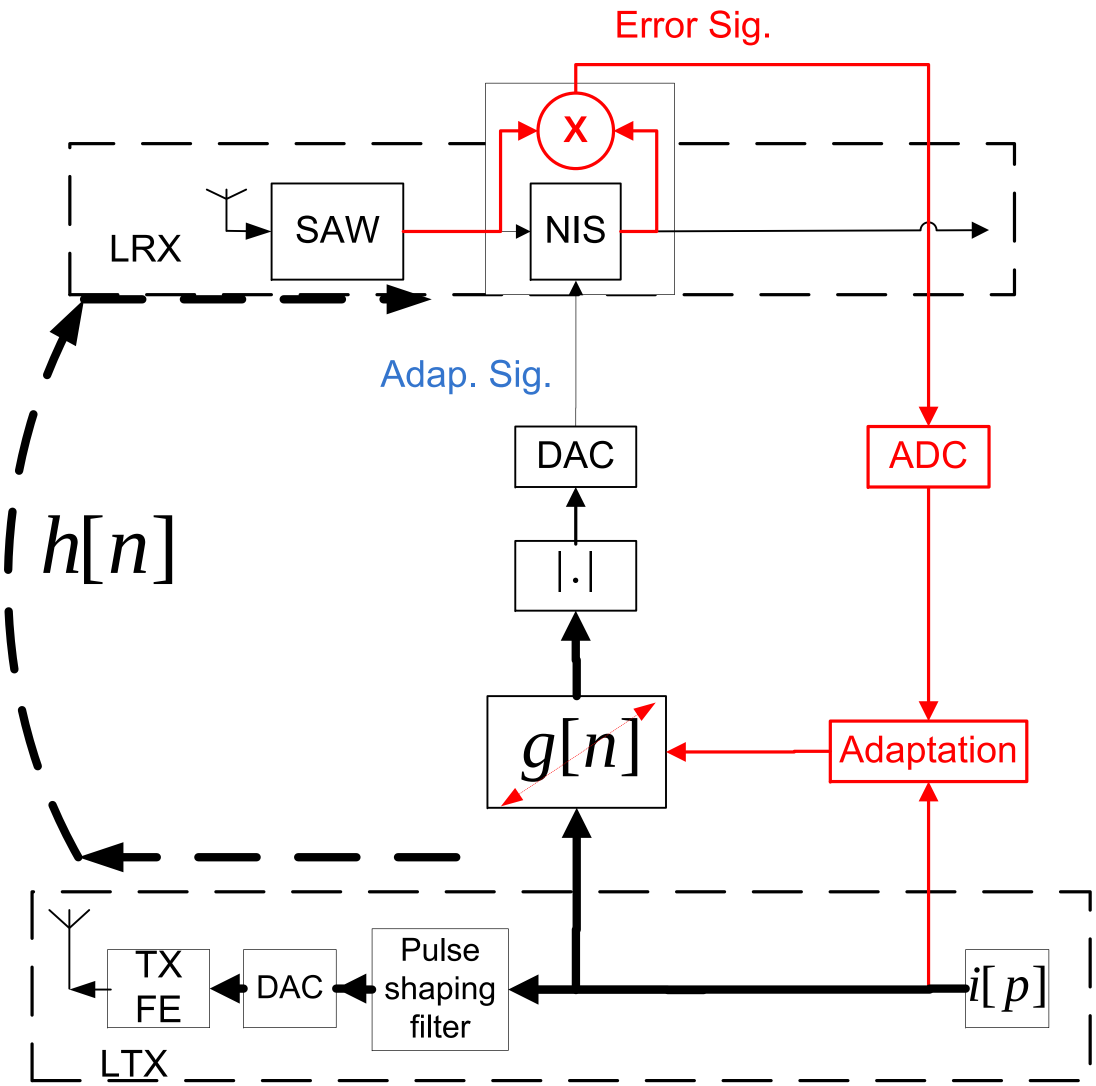
# NIS adaptation, closed-loop for constant modulus

- **The  input is dominated by the interference**
- **By cross-correlating the input and output, the envelope of the residual interference at the output can be measured.**

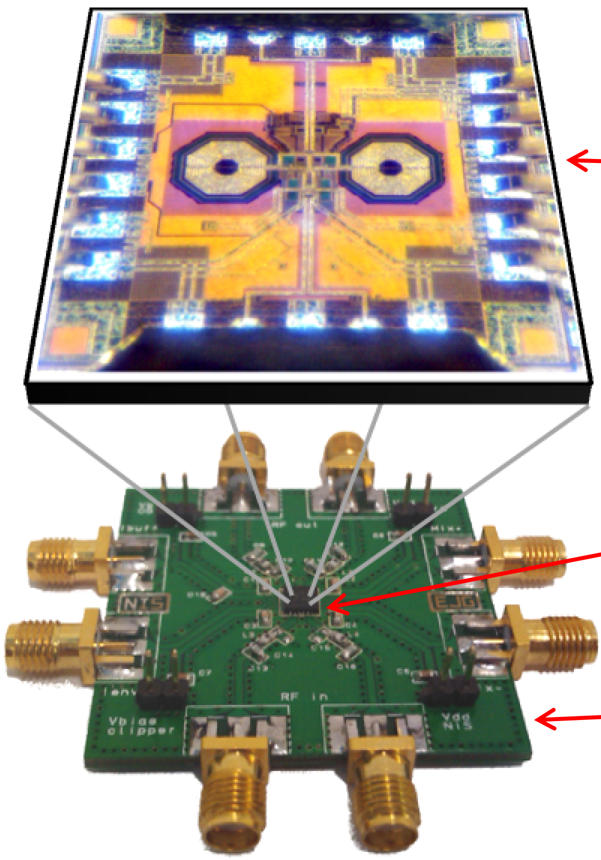


# NIS adaptation, FFW & Closed-loop



# Fabricated Prototype

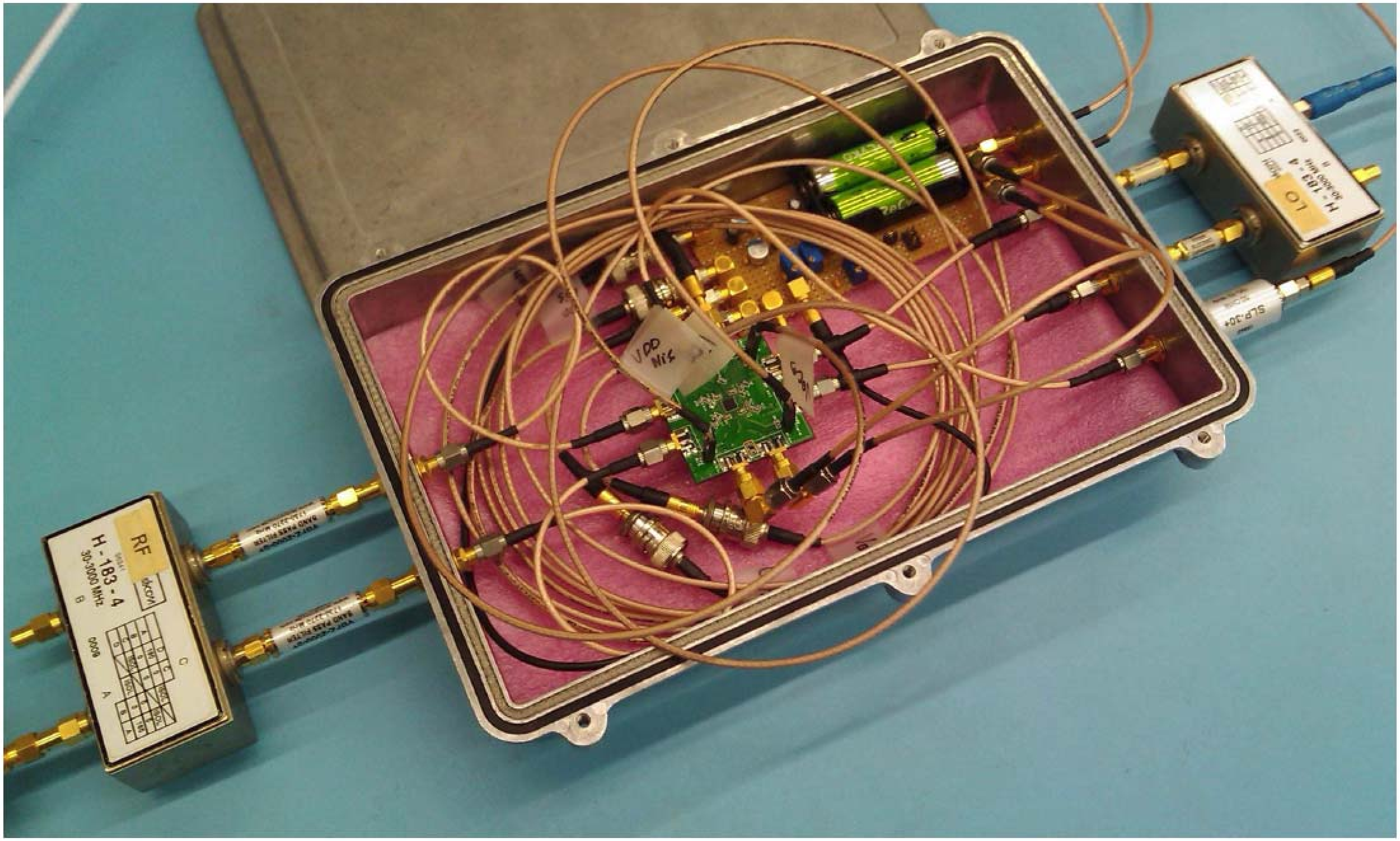


*(NIS + MIXER + Output buffers)*
*CMOS 140nm process*

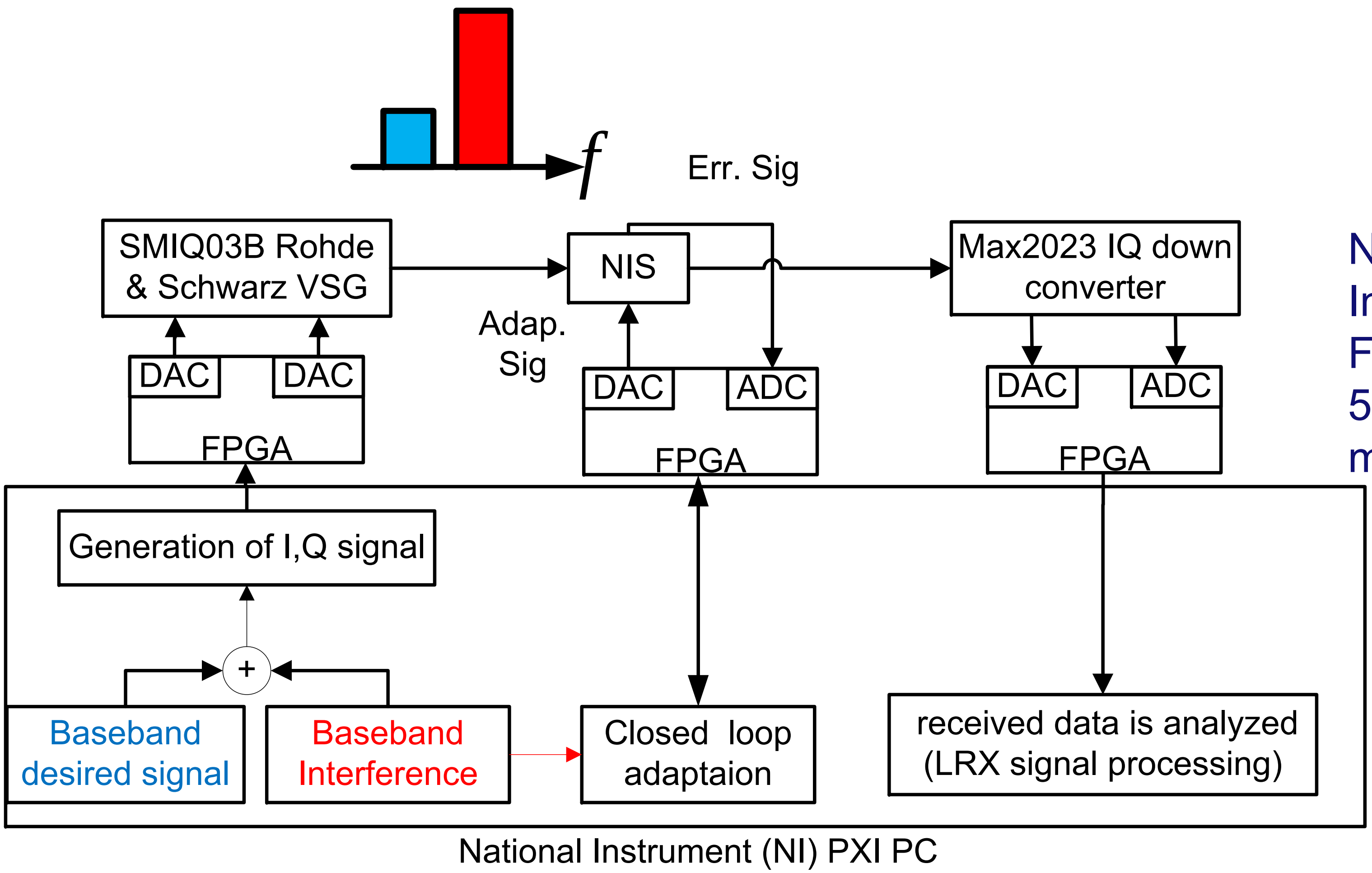
*HVQFN24 IC package*

*FR4 PCB*

# Fabricated Prototype in Faraday Cage + Power Supply / External Biasing Circuitry

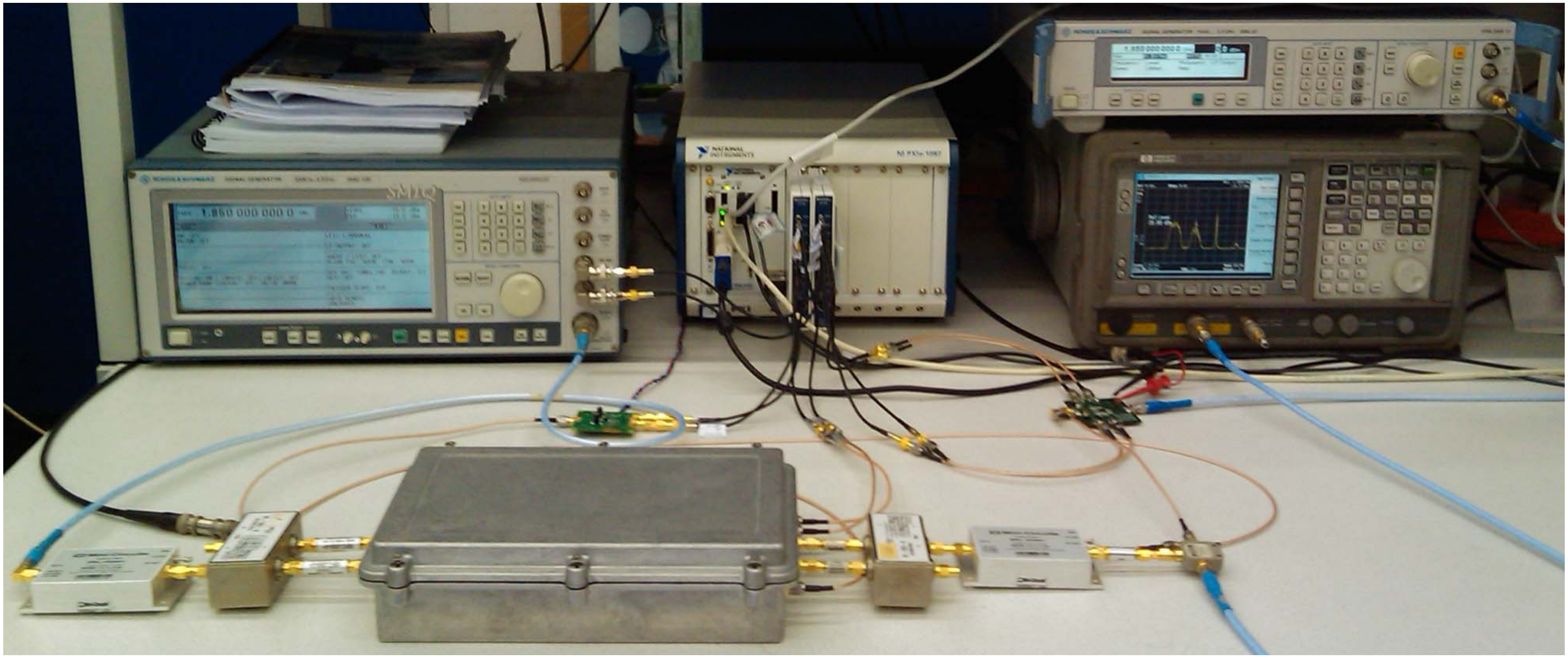


# Multimode Transceiver test bed




National Instrument FLEX RIO and 5781 adapter module

# Multimode Transceiver test bed



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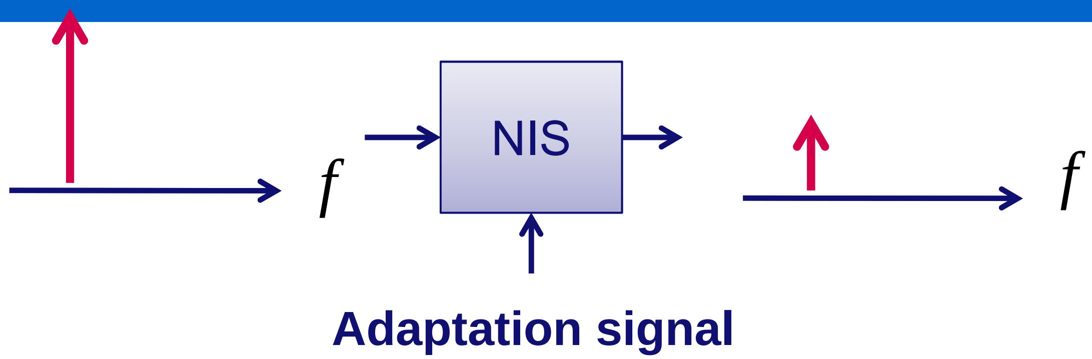
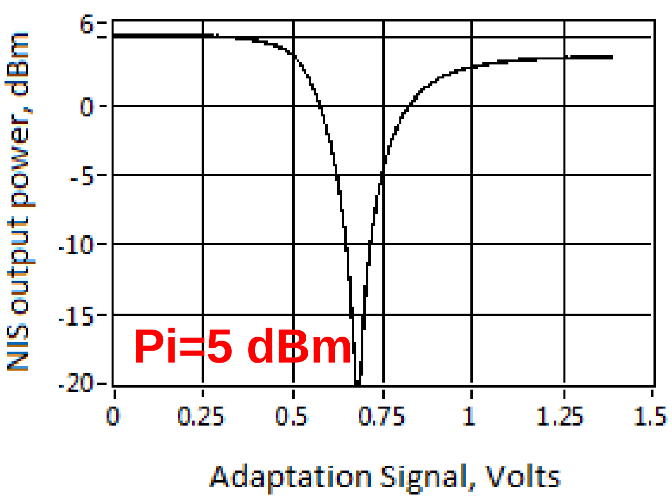
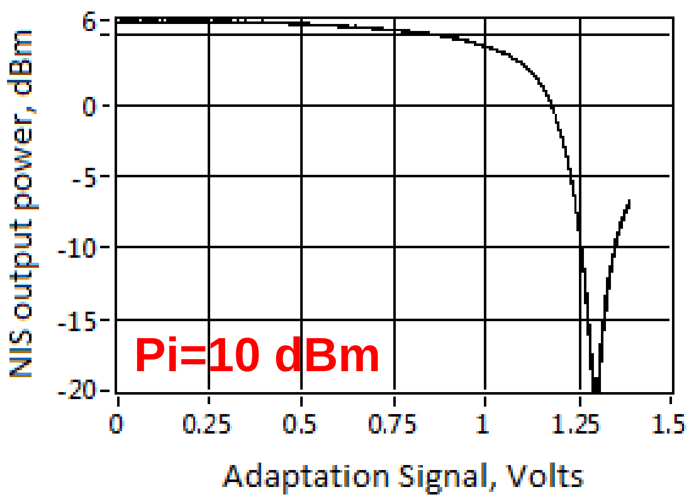
# Single tone input

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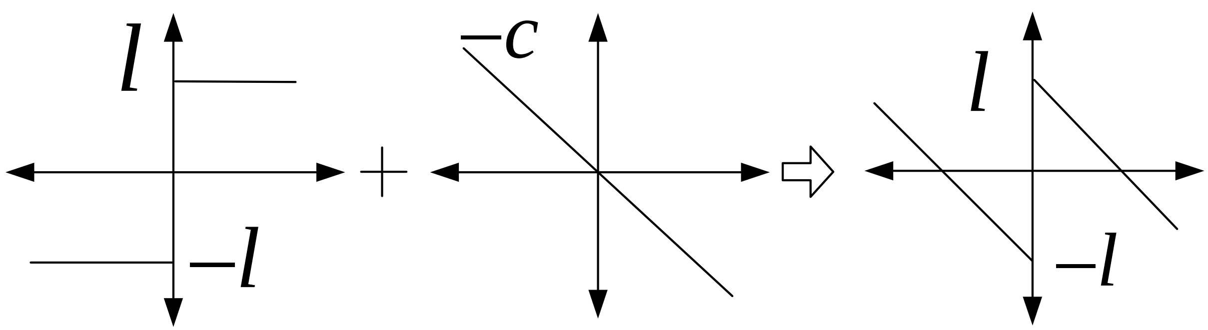
# Adaptation signal versus Ai
## Ideal NIS




$$\text{Adaptation signal}: l = \frac{\pi}{4} c A_i$$

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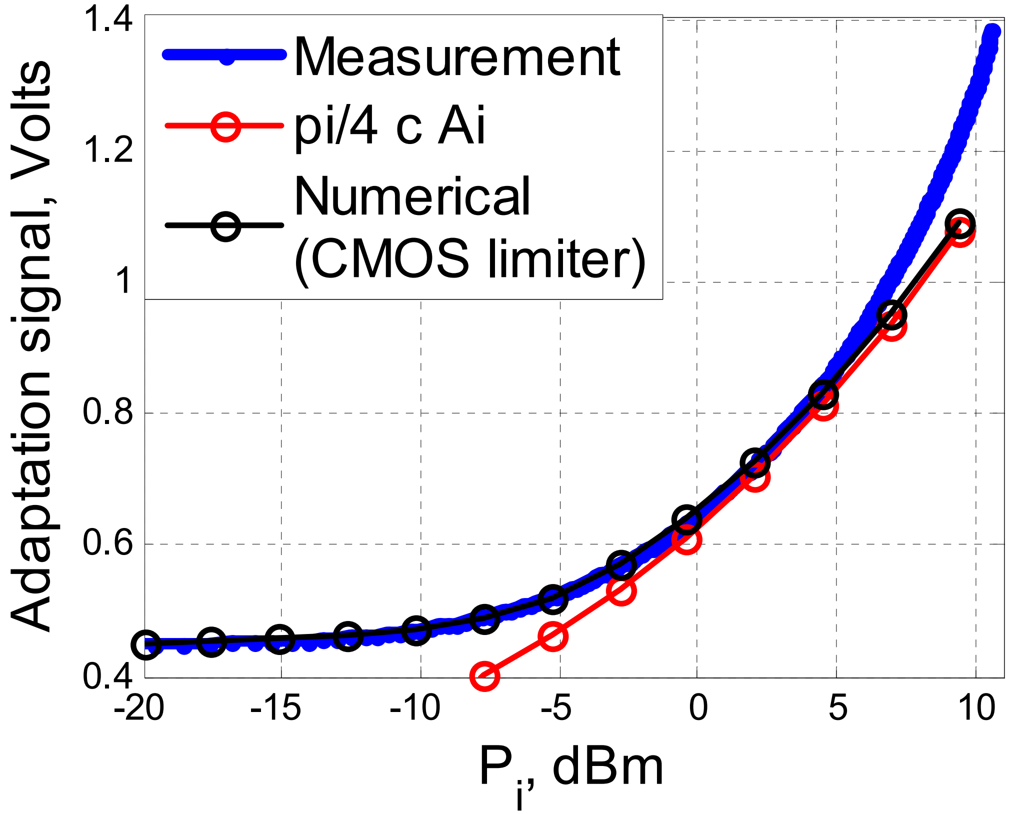
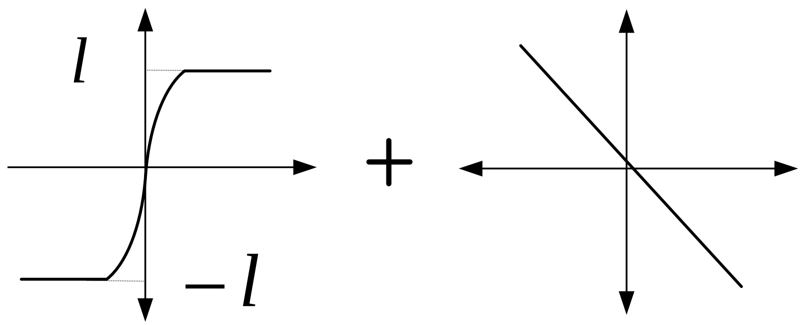
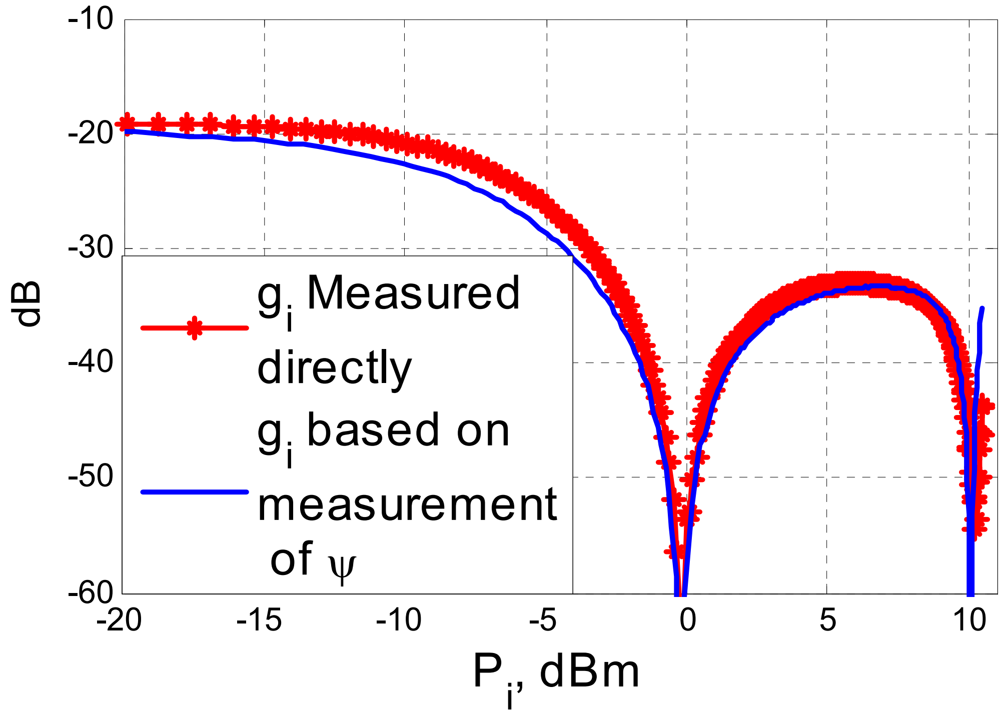
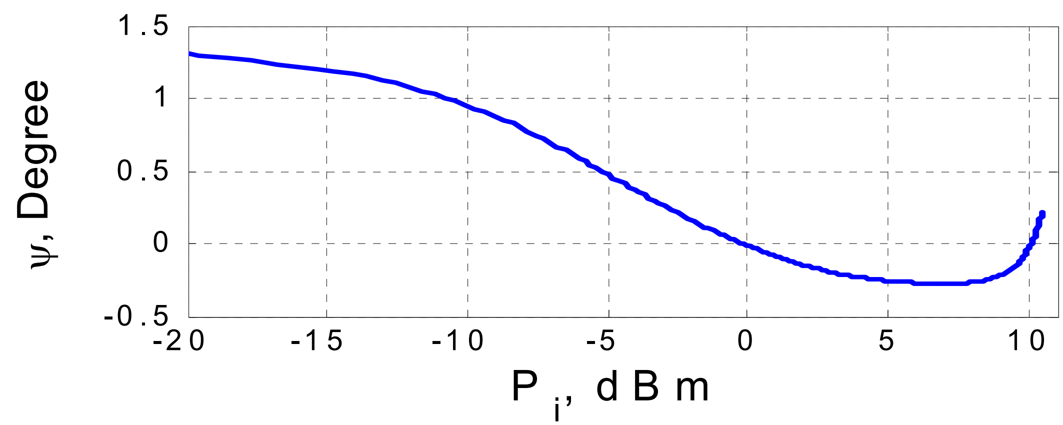
# Adaptation signal versus Ai
# Practical NIS

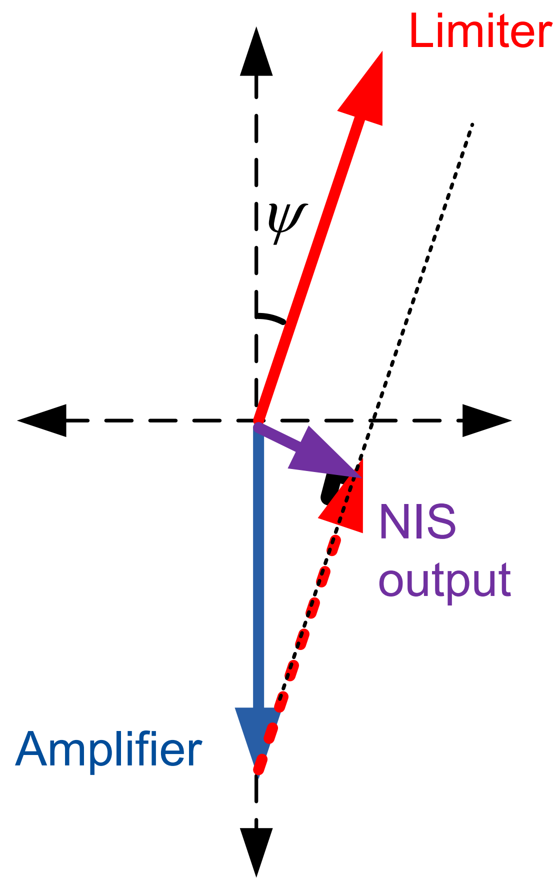


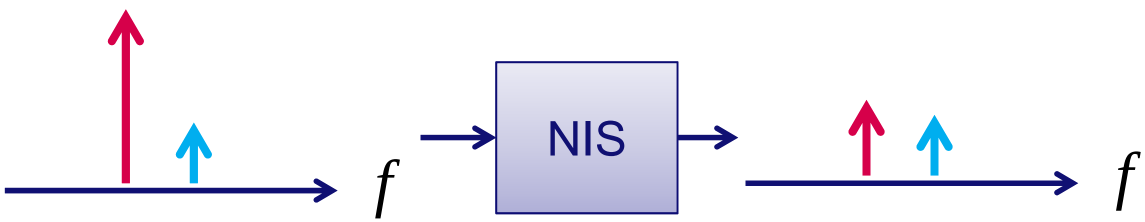
# Phase misalignment

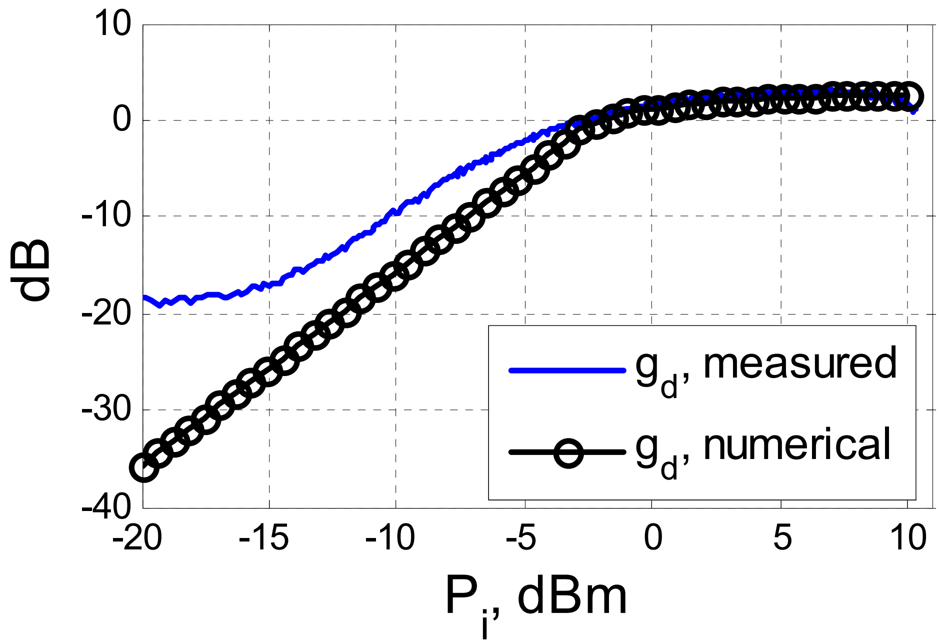


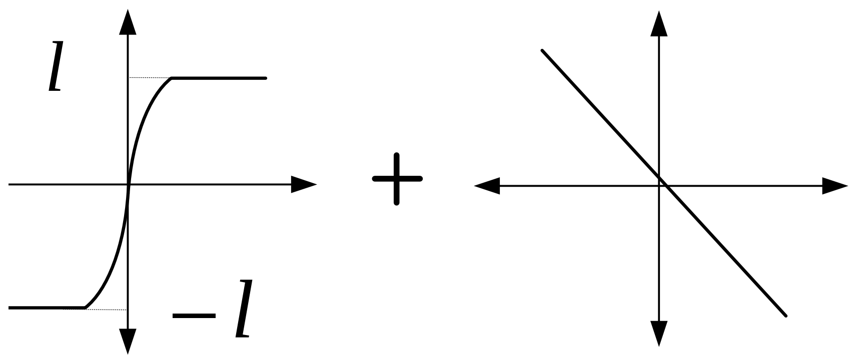



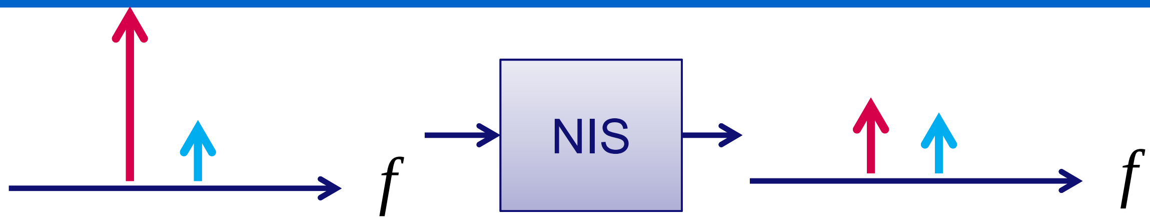
# Measurement of desired signal gain

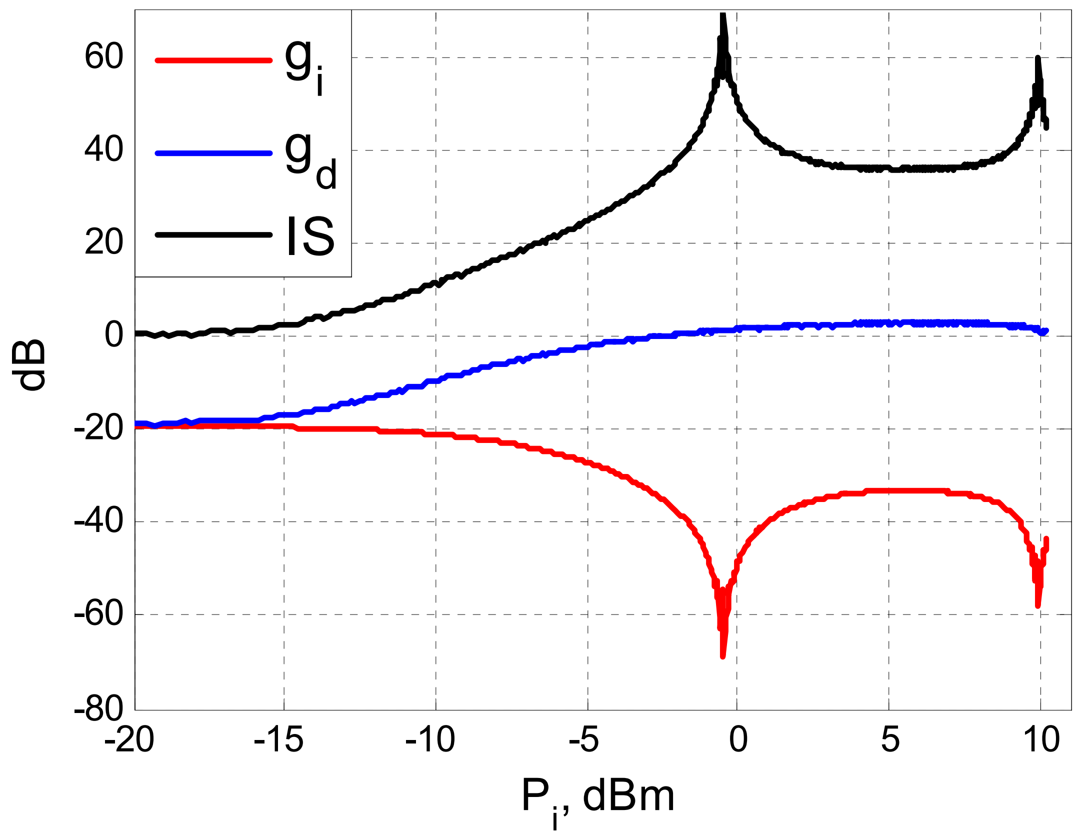


# Interference Suppression



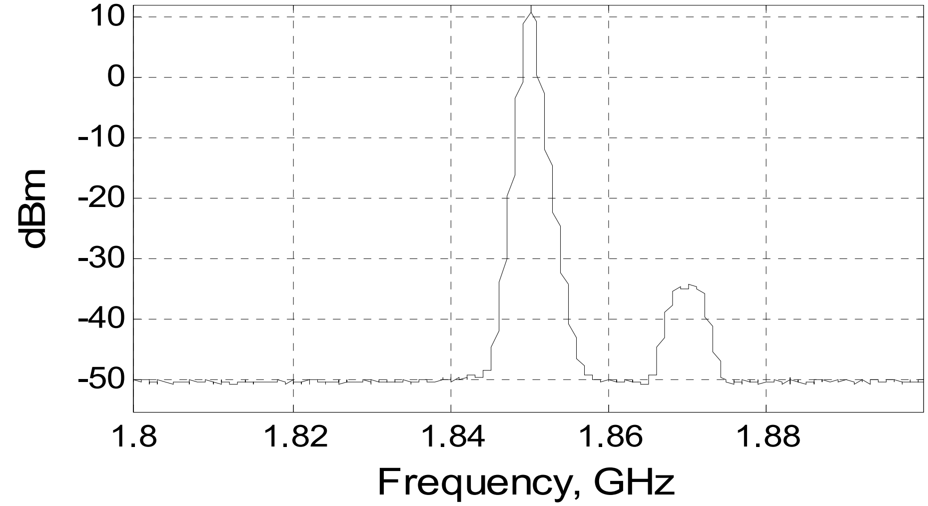

36 dB Interference Suppression over Pi (-2 to 11) dBm

# System evaluation for modulated signals

Input Spectrum:

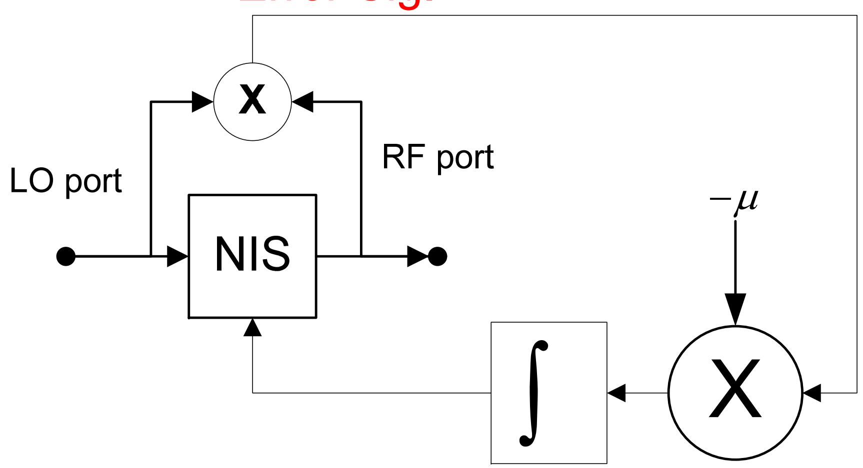
GMSK interference

QPSK desired signal

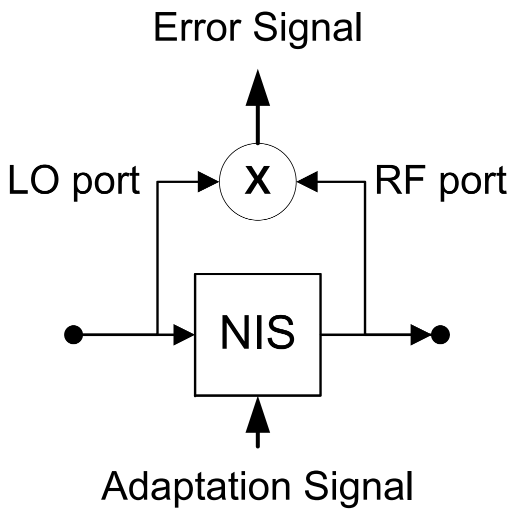


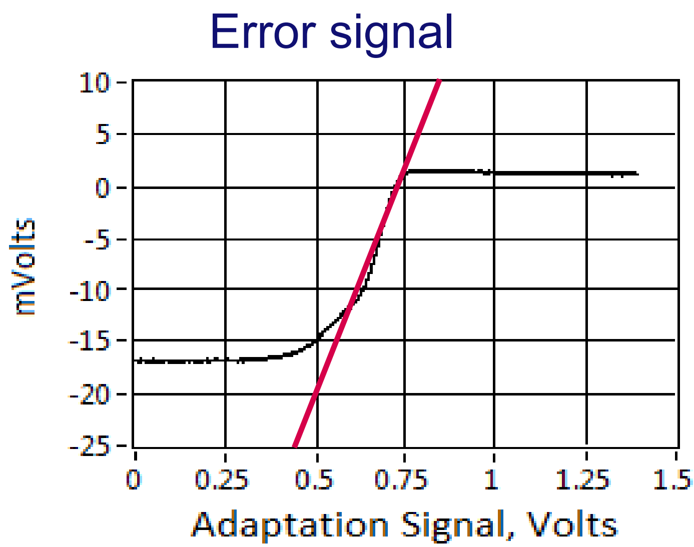

Closed-loop

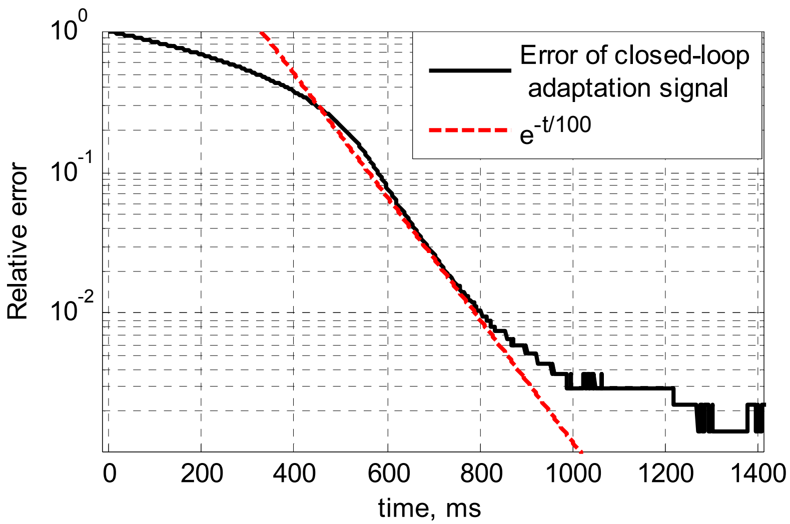
Adaptation



# Closed-loop adaptation



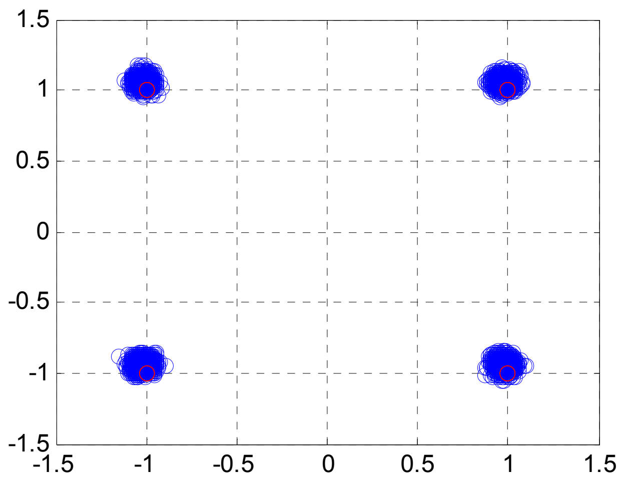

Time constant : 100 ms
Present results: limited by the PC
→ Future work: FPGA implementation

# NIS Output

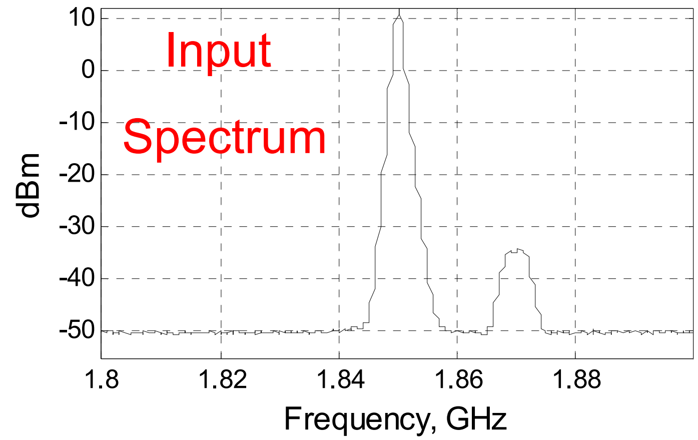
Input Spectrum:

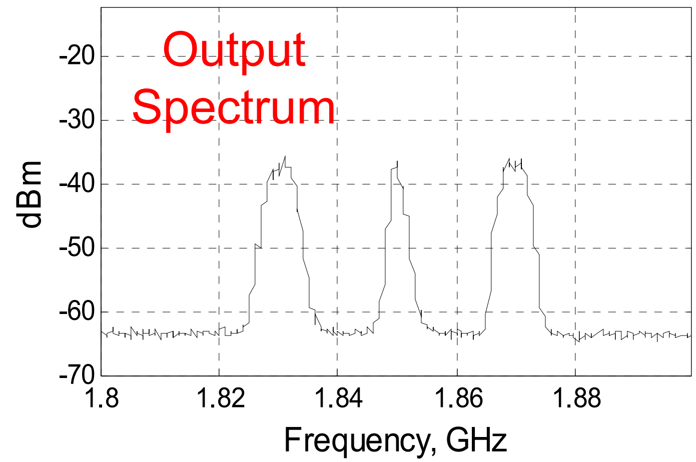
GMSK interference

QPSK desired signal




Received desired signal constellation



# Conclusion

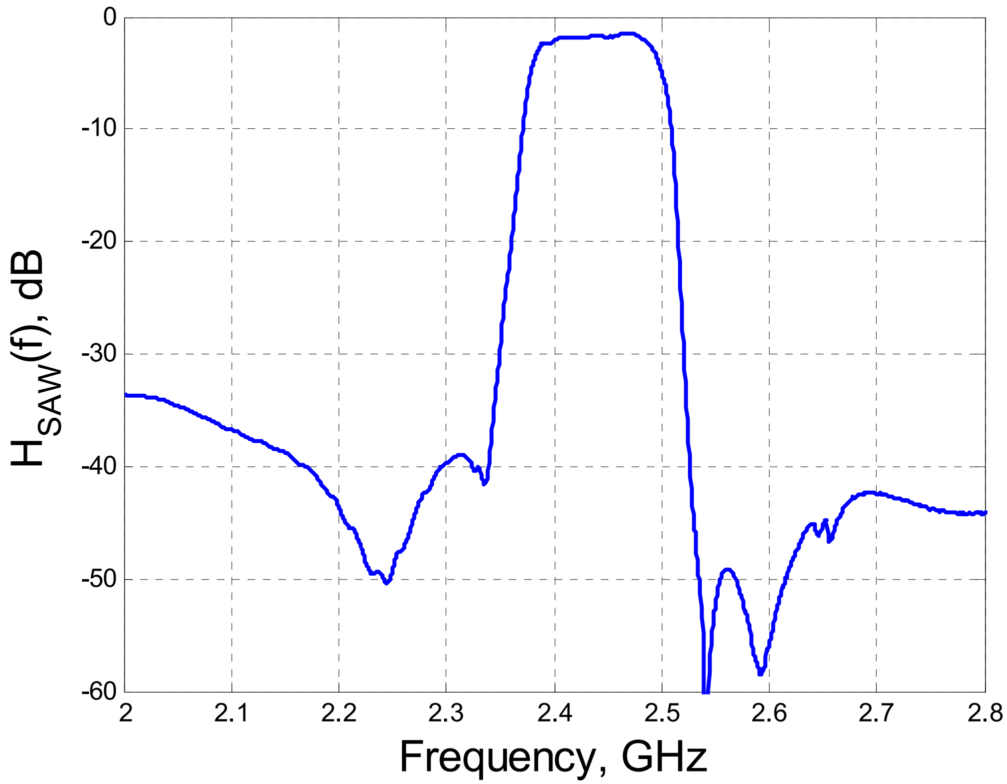
- In multimode transceivers we encounter large interferers.
- Handling the interferers by increasing the FE linearity increases the power consumptions.
- By using an adaptive nonlinearity we can suppress the interference at an early stage.
- The experimental results for an implementation of the NIS shows tens of dB of interference suppression.

# Questions:

- **Thank you for your attention.**

- **Extra Slides**

# SAW filter frequency response

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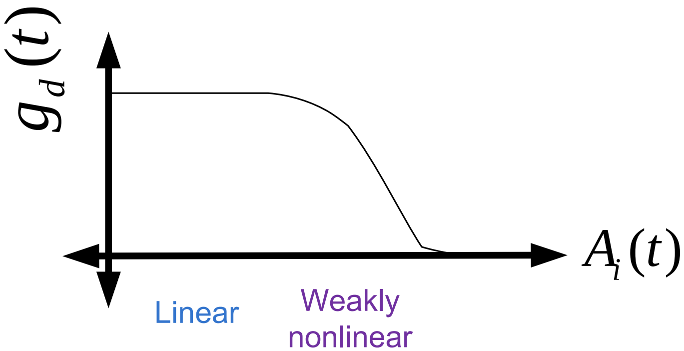
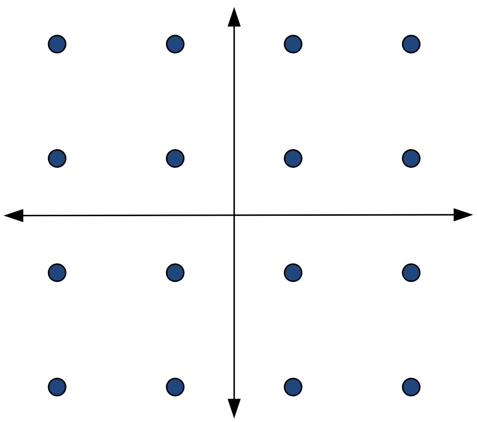
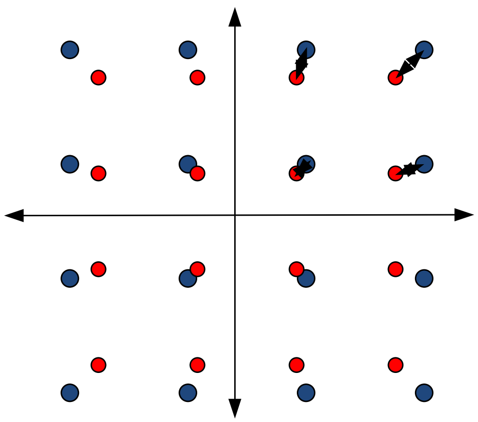
# Cross-modulation distortion



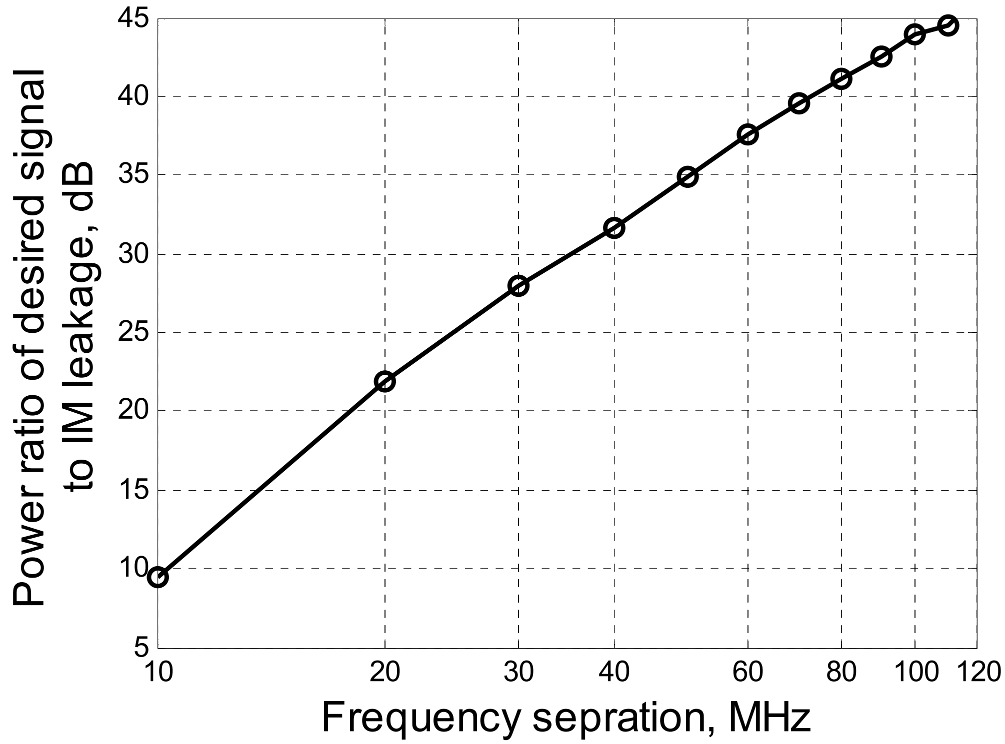


$$g_d(t) = \left(1 - \frac{3c}{2} A_i^2(t)\right)$$

- **The amount of CM depends on the Envelope of the received interferer and shape of Nonlinearity.**
- *Digital compensation of cross-modulation distortion in multimode transceivers* VTC Spring 2012, 6-9 May 2012.

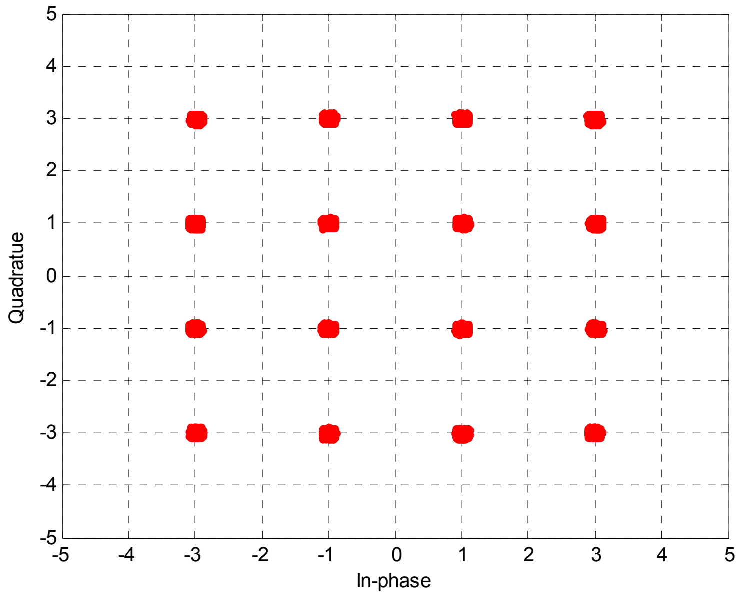
# IM leakage:

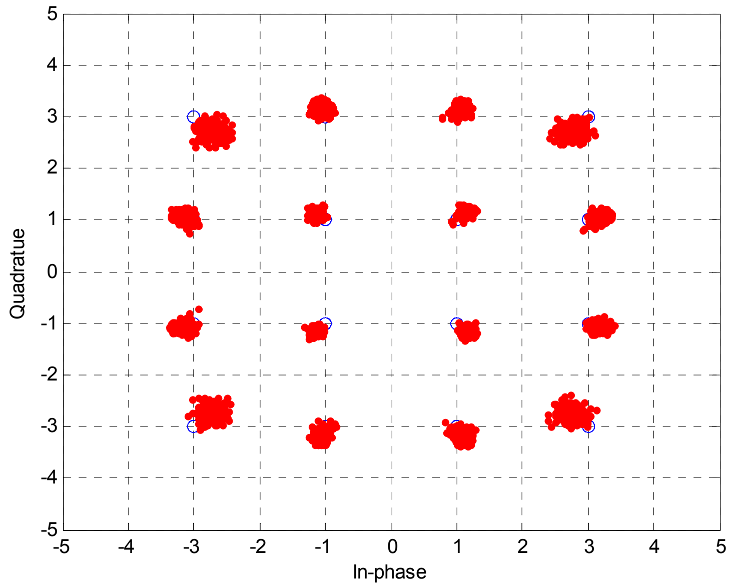
- **The IM leakage vanishes rapidly by increasing frequency separation.**



# Gain Variation Distortion (GVD),Constant modulus Interference:

Interference : Constant modulus.
Desired signal: Single carrier 16 QAM with raised cosine pulse shaping. No channel noise.




Input SIR = -10 dB
Δf=120 MHz

Input SIR = 0 dB (P1dB)

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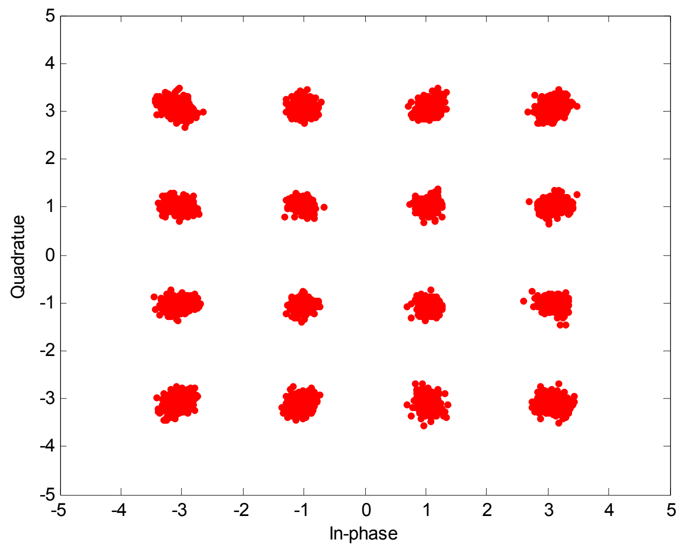
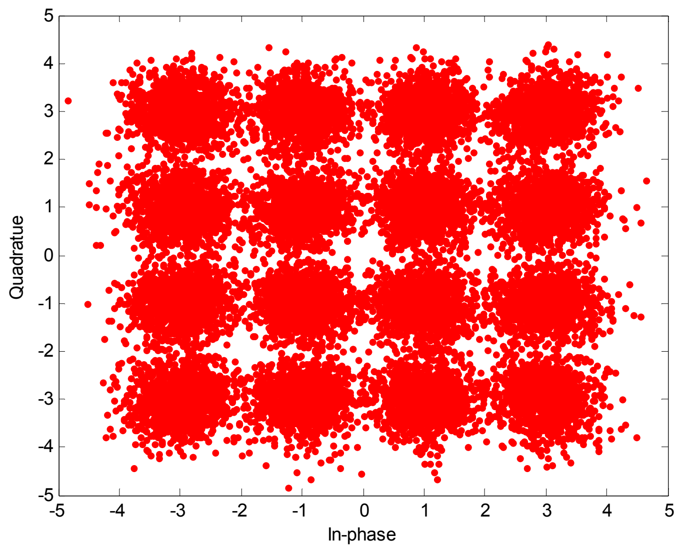
# Gain variation distortion, OFDM modulations

Both desired and interf.: OFDM with 64 sub cr.16 QAM. (Δf=120 MHz)

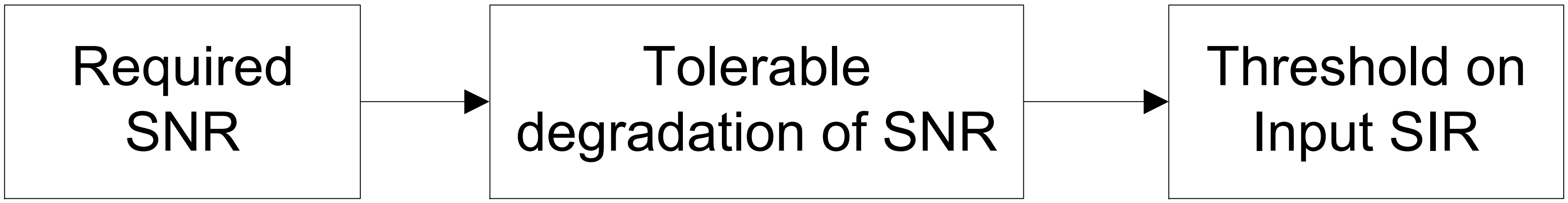



Input SIR = -30 dB




Input SIR = -10 dB

# Condition for negligible GVD



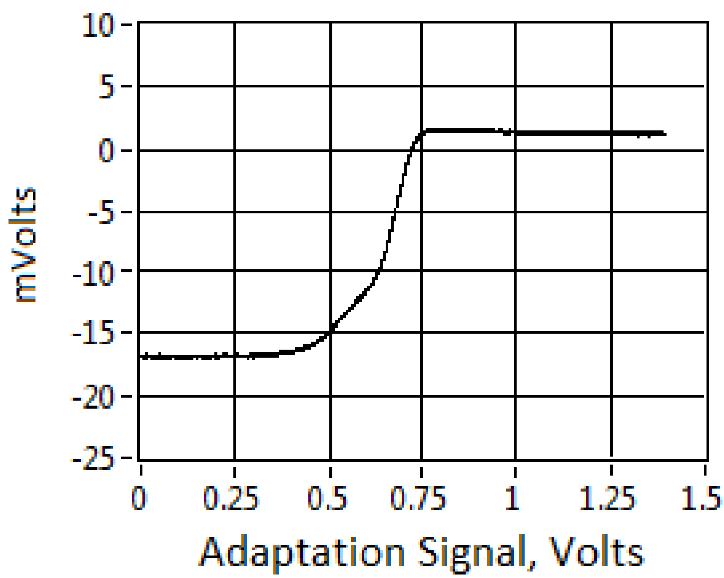

- **Example : 16 QAM modulation:**
  - **SER=$10^{-3}$ => SNR=17.6**
  - **0.1 dB degradation (1.2 x $10^{-3}$ )**
  - **Threshold on SIR at the NIS input : - 25 dB**

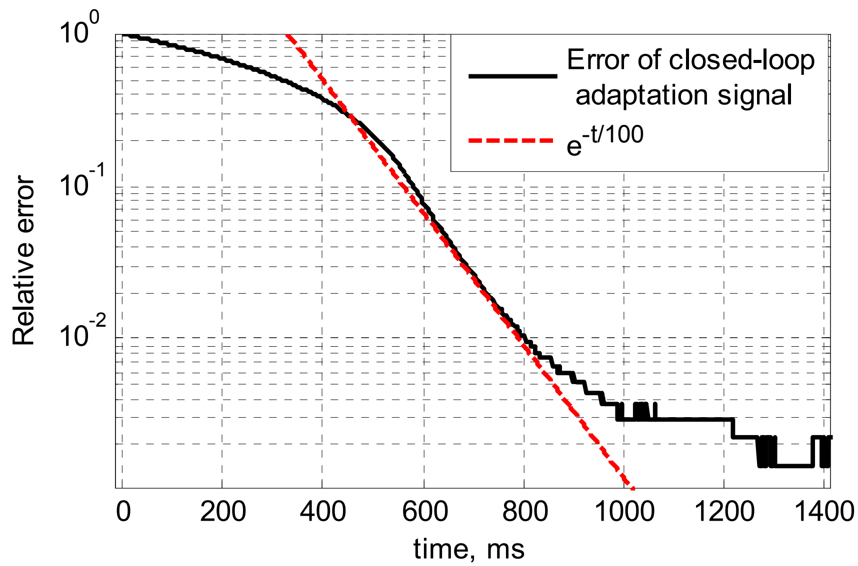
- **SIR < -25 dB => Use the NIS with negligible distortion**
- **SIR > -25 dB => Use the typical linear receiver. Since we are in weakly nonlinear region, we can use compensation methods**

# Erros signal and adaptation learning curve

- **Pi=5 dBm**

Time constant : 100 ms




Present results: limited by the PC
→ Future work: FPGA implementation

# Other circuit parameters

- IIP3 is at least 4dBm in that case that the large signal to be suppressed is larger than 0dBm.
  - (For ideal NIS: IIP3= Pint+10 dBm)
- Noise figure ~16 dB, can be improved in new designs.
- Power consumption: 35 mW to suppress a 10 dBm interference.

- *IEEE RFIC 2012, Erwin J.G. Janssen, Dusan Milosevic and Peter G.M. Baltus,'A 1.8GHz amplifier with 39dB frequency-independent smart self-interference blocker suppression'.*

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