DECAFE project

- Funded by STW.
- Technical Support from CATENA and NXP.
- Cooperation between UT and TU/e
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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.

SIR=-95dB

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Nonlinear interference Suppressor (NIS)

Principle of operation #1:

\[ f_i \]

\[ A_i \]

\[ t \]

\[ f \]

\[ cA_i \]

\[ f_i \]

\[ t \]

\[ l \]

\[ \frac{4l}{\pi} \]

\[ f_i, 3f_i, 5f_i \]
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. $G = c/2$

$$l = \frac{\pi}{4} cA_i$$
NIS in the presence of the desired signal

Des. Intrf. Intrf. G. = 0
Des. G. = -c/2

\[ l = \frac{\pi}{4} cA_i \]
Modulated inputs, Intermodulation product

\[ l(t) = \frac{\pi}{4} cA_i(t) \]

- 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 \( A_i \gg A_d \)
- The gain decreases when \( A_i \) approaches \( A_d \). Dependence of gain to \( A_i(t)/A_d(t) \) lead to nonlinear distortion

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

\( g_d(t), \text{ dB} \)
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.
- $g[n] : \text{FIR filter}$
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

**Diagram Description:**

- **LRX** to **SAW**
- **NIS** to **DAC**
- **Error Sig.** from **NIS**
- **Adap. Sig.** from **DAC** to **ADC**
- **h[n]** input
- **g[n]** output
- **TX FE** and **LTX**
- **Pulse shaping filter**
- **i[p]** output

**Symbols:**

- X
- | |
- DAC
- ADC
- Adaptation
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

SMIQ03B Rohde & Schwarz VSG

NIS

Max2023 IQ down converter

National Instrument (NI) PXI PC

Generation of I,Q signal

Baseband desired signal

Baseband interference

Closed loop adaptation

received data is analyzed (LRX signal processing)
Multimode Transceiver test bed
Single tone input

Adaptation signal

\[ P_i = 5 \text{ dBm} \]

\[ P_i = 10 \text{ dBm} \]
Adaptation signal versus $Ai$

Ideal NIS

Adaptation signal: $l = \frac{\pi}{4} cA_i$
Adaptation signal versus Ai
Practical NIS

Adaptation signal, Volts

-20 -15 -10 -5 0 5 10

Pi, dBm

Measurement
pi/4 c Ai
Numerical (CMOS limiter)

l

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Phase misalignment

\[ g_i \text{ Measured directly} \]
\[ g_i \text{ based on measurement of } \psi \]

\[ \psi, \text{ Degree} \]

\[ P_i, \text{ dBm} \]

\[ \psi, \text{ Degree} \]

\[ P_i, \text{ dBm} \]

Limiter
NIS output
Amplifier
Measurement of desired signal gain

\[
\begin{align*}
\text{dB} & \quad \text{P}_i, \text{dBm} \\
-40 & \quad -20 \\
-30 & \quad -15 \\
-20 & \quad -10 \\
-10 & \quad -5 \\
0 & \quad 0 \\
10 & \quad 5 \\
20 & \quad 10 \\
30 & \quad 15 \\
40 & \quad 20 \\
\end{align*}
\]

\[g_d, \text{measured} \quad \text{g}_d, \text{numerical}\]
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

Error Signal

LO port → RF port

NIS

Adaptation Signal

Error signal

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

![Graph of SAW filter frequency response](image-url)
Cross-modulation distortion

The amount of CM depends on the Envelope of the received interferer and shape of Nonlinearity.


\[
g_d(t) = \left(1 - \frac{3c}{2} A_i^2(t)\right)
\]
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
$\Delta f=120$ MHz

Input SIR = 0 dB (P1dB)
Gain variation distortion, OFDM modulations

Both desired and interf.: OFDM with 64 sub carrier 16 QAM. \((\Delta f=120 \text{ MHz})\)

Input SIR = -30 dB

Input SIR = -10 dB
**Condition for negligible GVD**

- Example: 16 QAM modulation:
  - \( \text{SER}=10^{-3} \Rightarrow \text{SNR}=17.6 \)
  - 0.1 dB degradation \((1.2 \times 10^{-3})\)
  - Threshold on SIR at the NIS input: -25 dB

- \( \text{SIR} < -25 \text{ dB} \Rightarrow \text{Use the NIS with negligible distortion} \)
- \( \text{SIR} > -25 \text{ dB} \Rightarrow \text{Use the typical linear receiver. Since we are in weakly nonlinear region, we can use compensation methods} \)
Erros signal and adaptation learning curve

- $P_i = 5$ dBm

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

Time constant: 100 ms
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.
