Multi-Band / Multi-Standard Radio Front-Ends

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6 November 2014

Outline

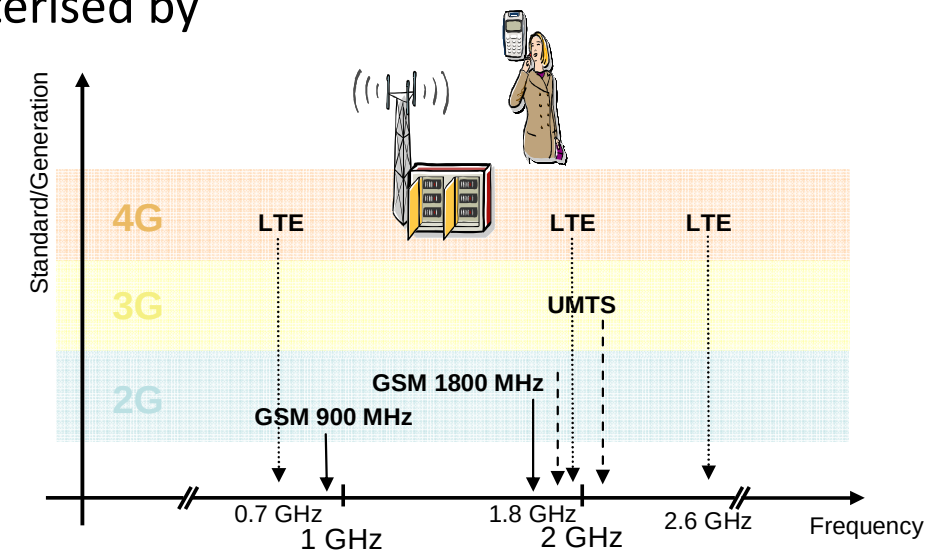
- Situation & Motivation
- Transceiver Architectures
- Flexible Power Amplification
- Dual-Band Filters
- Neuronal Networks
- Switch Mode Power Amplifier
- Summary

Situation & Motivation

Today's radio communication is characterised by

- Different markets
  - Europe, North America, China, ...
- Increased number of air interfaces
  - Standards: GSM, UMTS, LTE, ...
  - Bands: 900 MHz, 2.1 GHz, ...

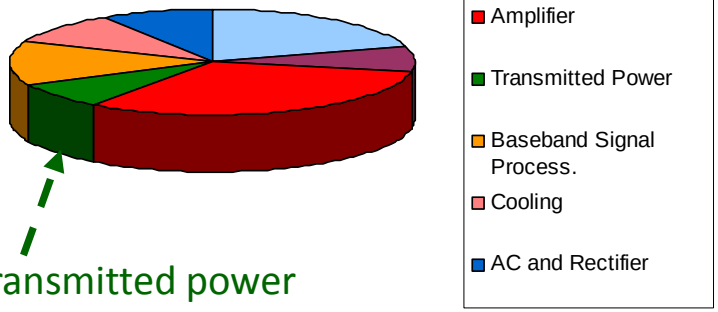
⇨ large required product portfolio!



- In order to increase flexibility and reusability and thus increase sustainability, especially of the RF transceiver hardware, *multi-band* and *multi-standard* capable building blocks are required
- Appearing technical challenges/issues
  - Bottlenecks: amplifier (bandwidth – efficiency), filter (quality – effort), ...
  - Different standards require different output power levels (related to signal PARs)

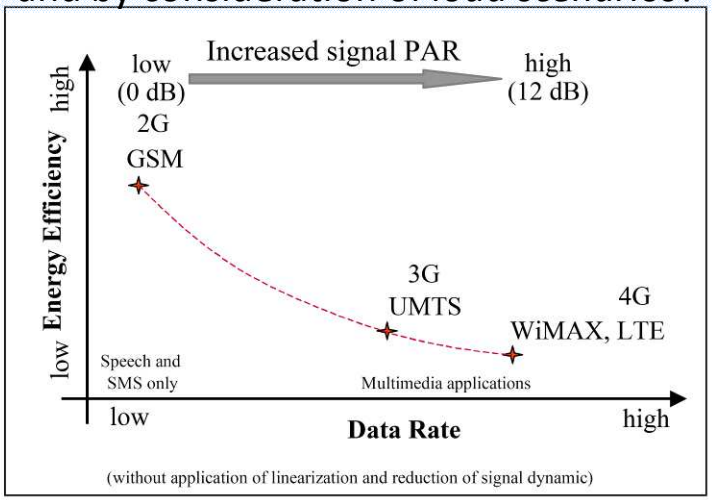
Situation & Motivation

Power distribution within a transceiver



A hugh portion of the BS losses are caused by the power amplifier module!

This becomes even worse for *modern communication standards* and by consideration of *load scenarios*!

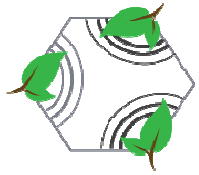


PA Energy Efficiency influences

- Environment
- OPEX
- CAPEX
- Cooling effort
- Design and size

Overview of Dual-Band TRX Activities

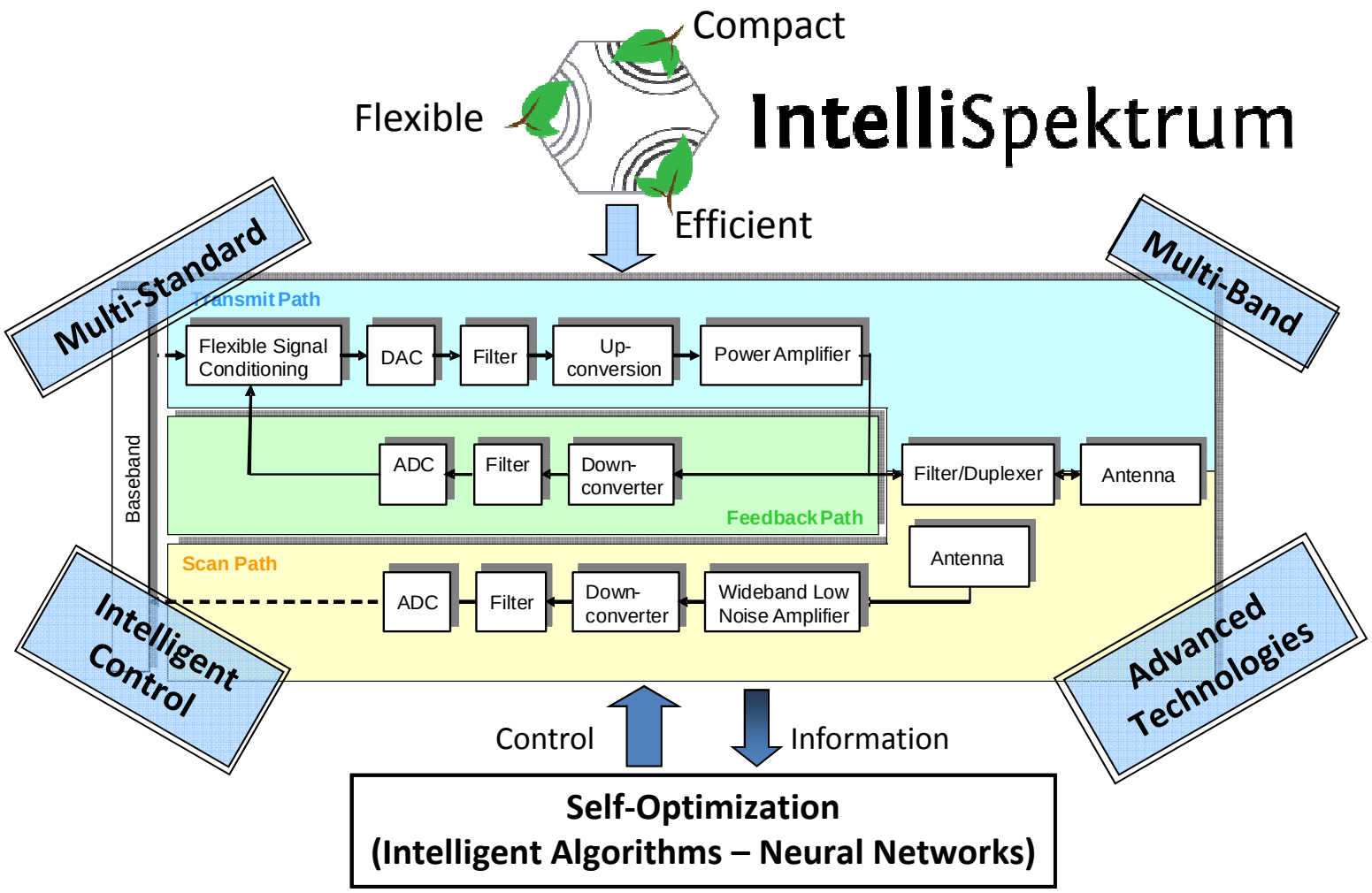
- Identification of appropriate transceiver architectures
  - Flexible, multi-band capable, …
  - Identification and comparison of promising architectures
- Investigation and simulation of concepts
  - Creation of simulation line-up and investigation of concepts
  - Deriving of component requirements and specifications
  - Parameter and interfaces for intelligent control



IntelliSpektrum

- Advanced components
  - GaN based power amplifier ⇨ project partner FhG-IAF Freiburg
  - GaN based low noise amplifier ⇨ project partner FhG-IAF Freiburg
- Development and implementation of intelligent algorithms
- Design, realization and characterization of demonstrators

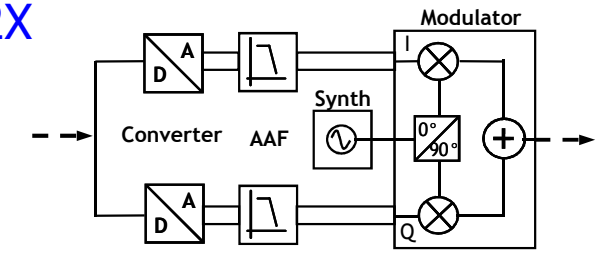
RF Transceiver Concept



Frequency Conversion Concepts

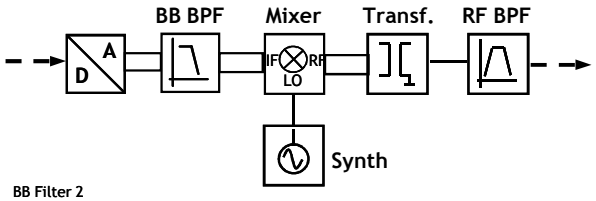
- Direct-Up Conversion
  - Using I/Q modulator
  - Flexible in carrier frequency
  - Requires compensation of modulator non-idealities
  - Supporting high signal bandwidths

2X

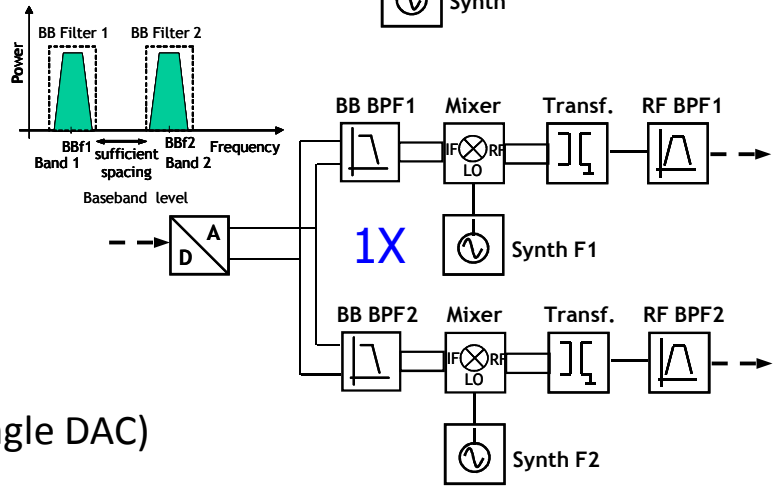


- Heterodyning
  - Using a mixer
  - RF filter required (carrier, image)
  - Supporting medium signal bandwidths
  - Reduced power consumption (single DAC)

2X



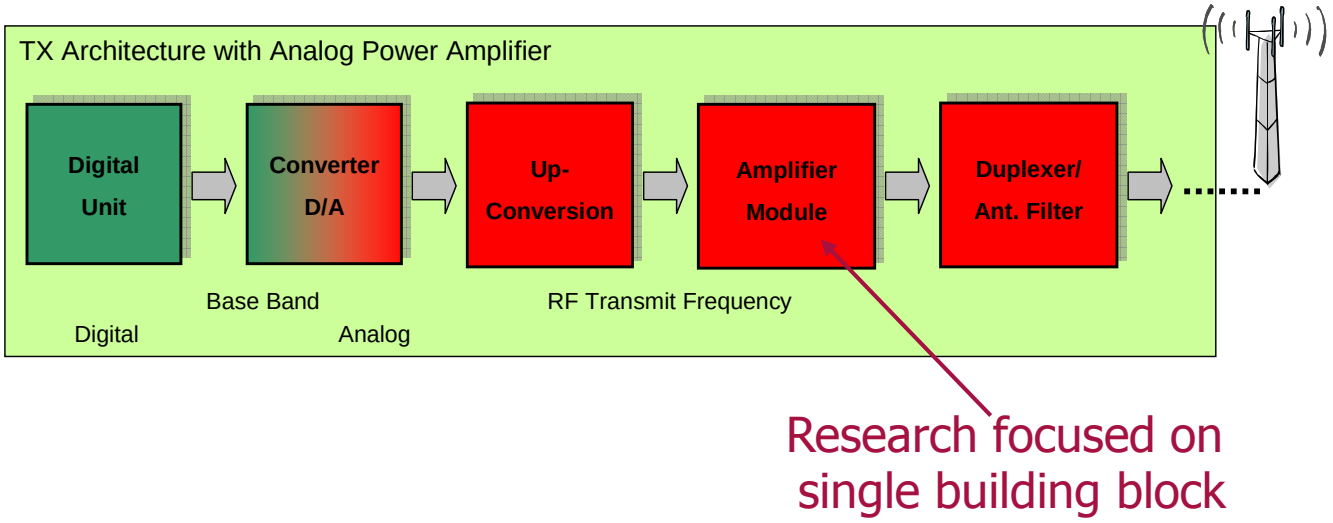
- Heterodyning using Signal Separation
  - Using a mixer
  - Specific baseband and RF filter required
  - Reduced signal bandwidths supported
  - Additionally reduced power consumption (single DAC)



required number for simultaneous dual band operation

Flexible Power Amplification – System Approach

- Dedicated digital and analog building blocks
- Trend towards higher integration
- Power amplifier and antenna filter are still dedicated building blocks



- In the past years, amplifier research was focused on multi-band capability and energy efficiency - technology and concepts

Flexible Power Amplification – System Approach

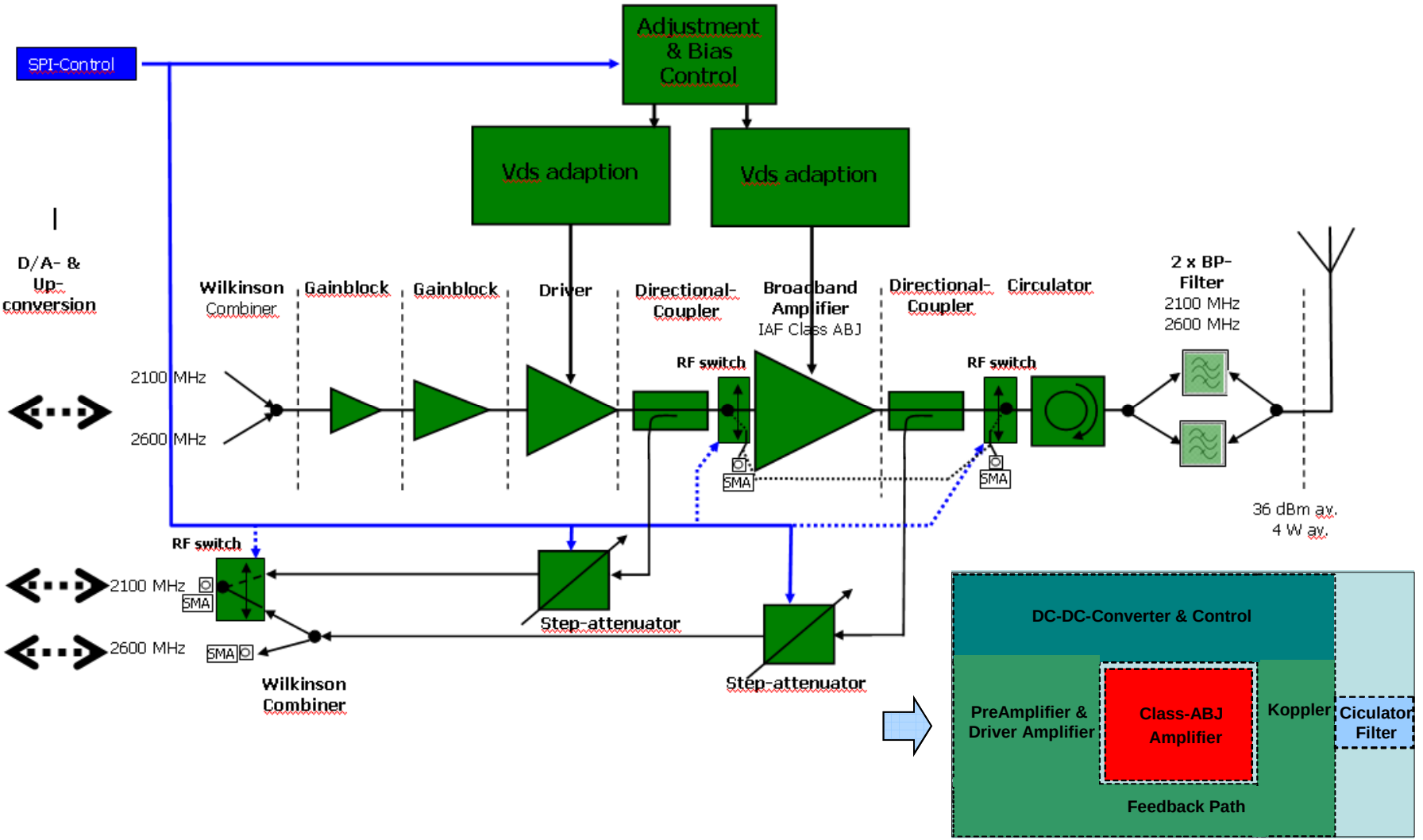
Main Building Blocks

- Dual-band pre-amplifier and Class-ABJ power amplifier
- Wideband circulator and dual-band filter
- Feedback paths supporting adaptive pre-distortion
- Controllable DC/DC converters (driver amplifier and final amplifier)

Main Features

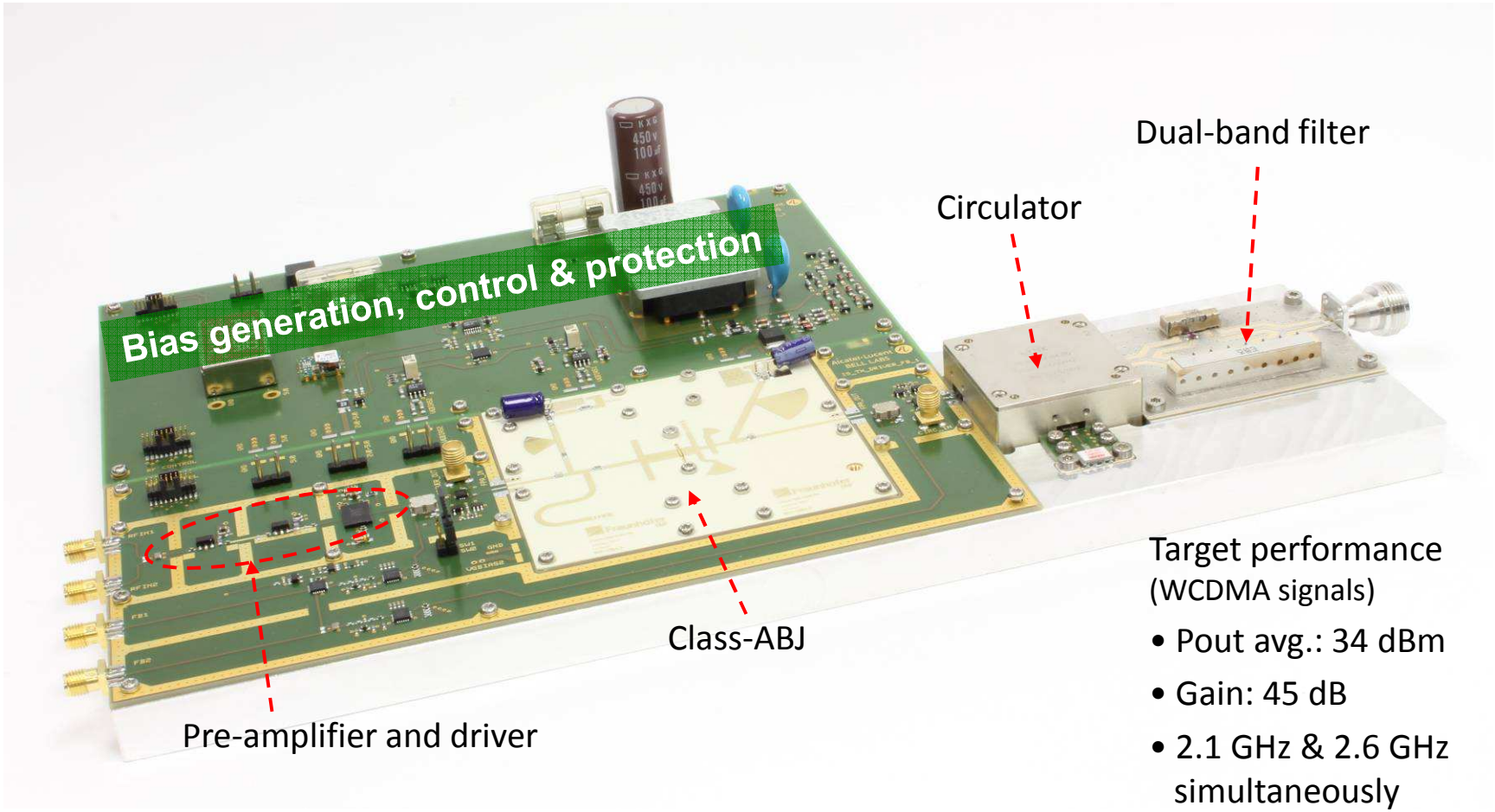
- Flexible bias control and final amplifier stage by-passing
- Interfaces for neural control and optimization
- Measurement of DC power consumption (driver amplifier and final amplifier)
- On-board supply voltage generation and power amplifier bias protection

Flexible Power Amplification – System Approach



IntelliSpektrum Amplifier Module

Flexible Power Amplification – System Approach

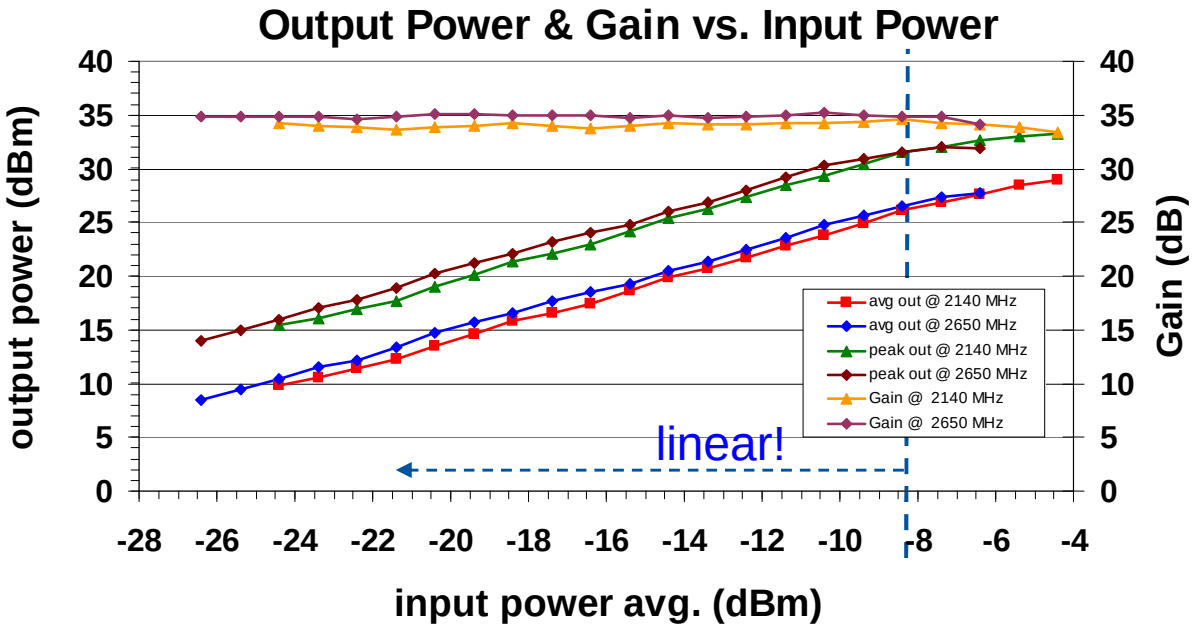


Target performance
(WCDMA signals)

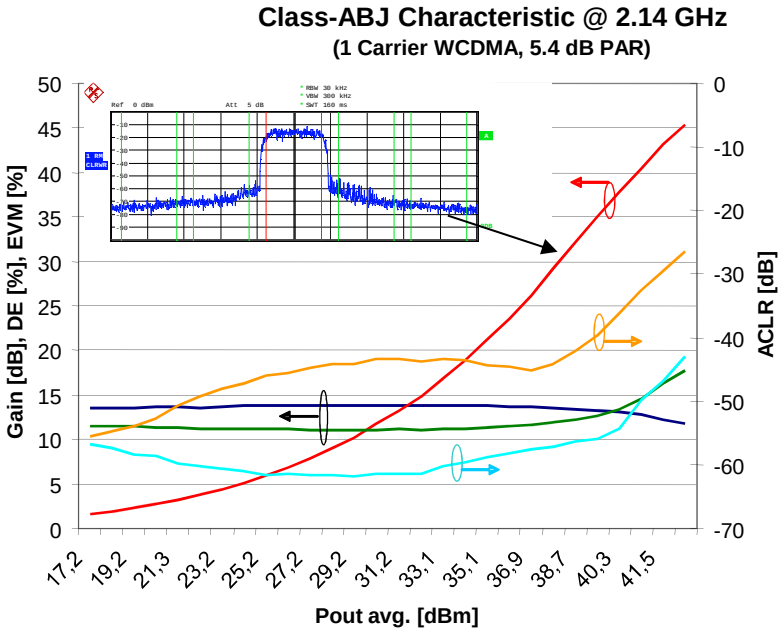
- Pout avg.: 34 dBm
- Gain: 45 dB
- 2.1 GHz & 2.6 GHz simultaneously

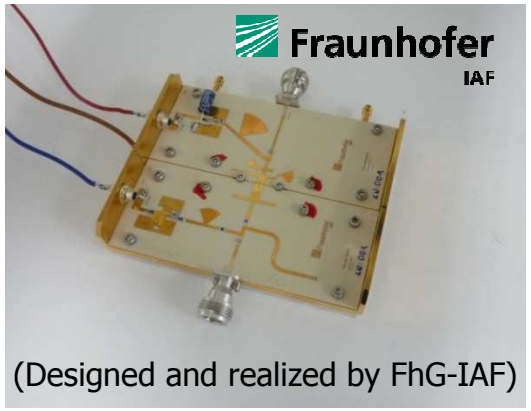
Pre-Amplifier Line-Up

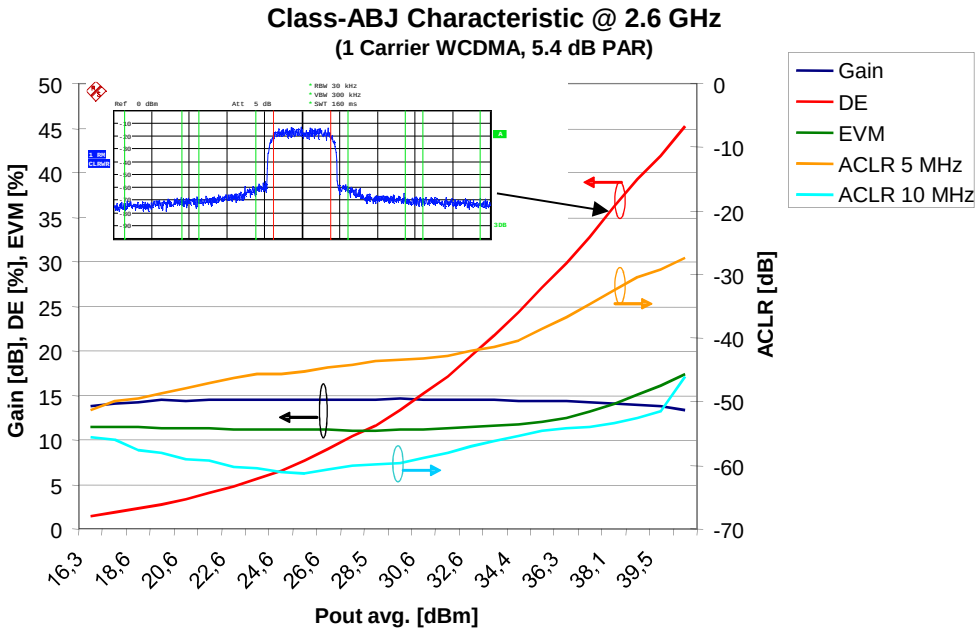
- Wideband capable, covering 2.1 GHz & 2.6 GHz band
- Linear characteristic
- 26 dBm avg. linear output power (WCDMA)
- Three amplifier stages - at least 33 dB total gain
- Supply voltage control for driver amplifier



Class-ABJ Power Amplifier







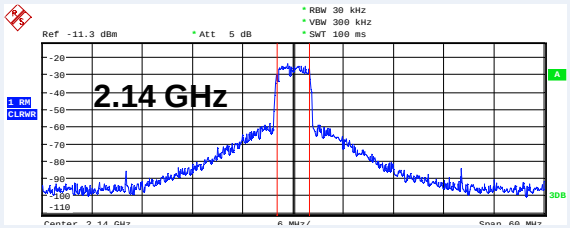
Energy efficient wideband amplifier: (WCDMA)

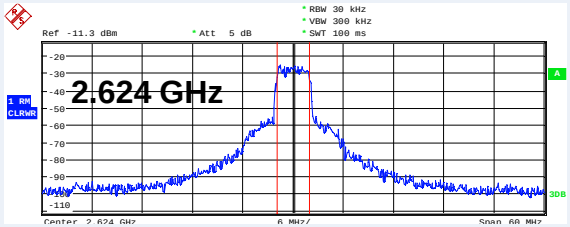
- 2.14 GHz: 33.4 % DE @ 39.2 dBm avg.
- 2.6 GHz: 38.5 % DE @ 38.6 dBm avg.
- digital pre-distortion used

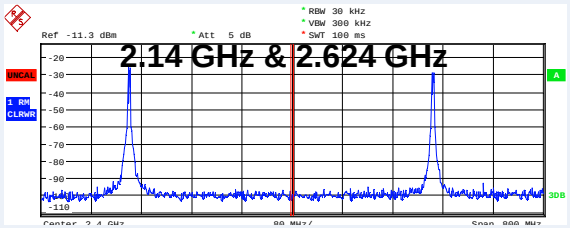
Flexible Power Amplification – Measurement Results

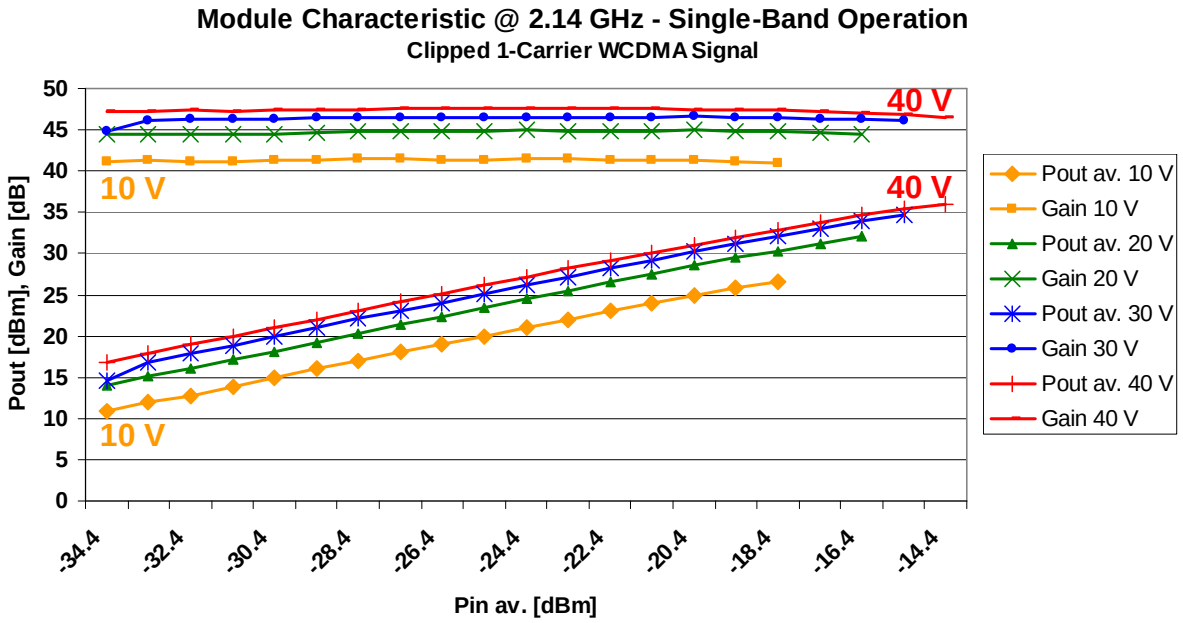
Dualband Operation

Without application of linearization!



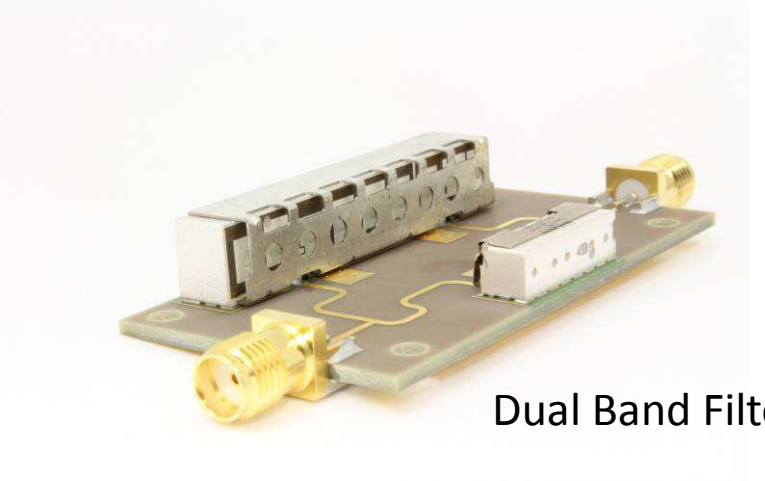




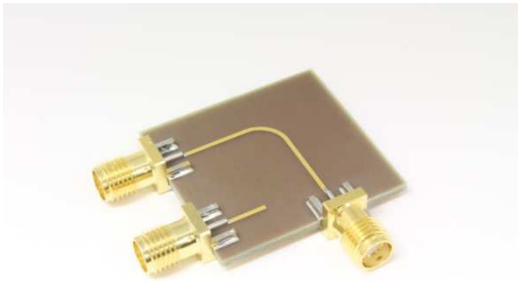


- Controllable supply voltages
- Gain @ single band operation : > 40 dB up to 47 dB
- Pout avg. @ sing. Band operation: up to 35 dBm (no linearization applied yet!)
- 2.1 GHz & 2.6 GHz simultaneous operation

Dual-Band Filter

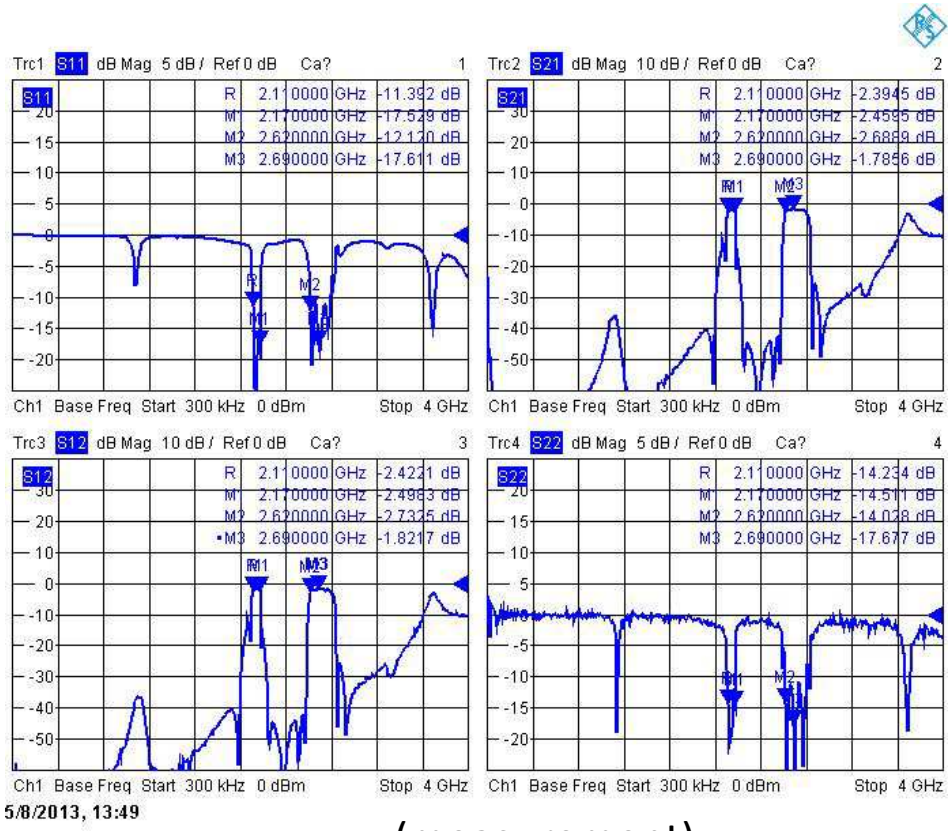


Dual Band Filter



Deembedding Structures

Filter realized on FR4 substrate



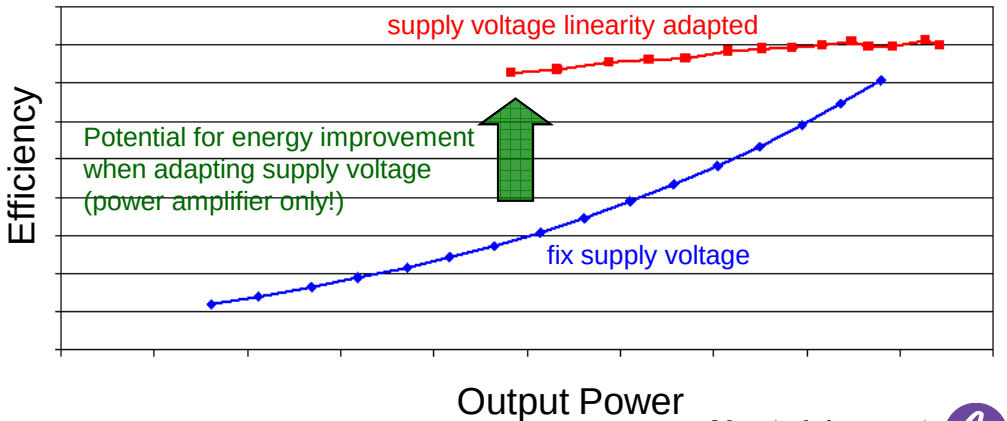
(measurement)

Extended Amplifier Characterization

Extended Amplifier Characteristics

- Detailed characterization (e.g. Pin & Vds sweep)
- Analysis
- Assessment of potential for energy improvement

Amplifier Efficiency Characteristic

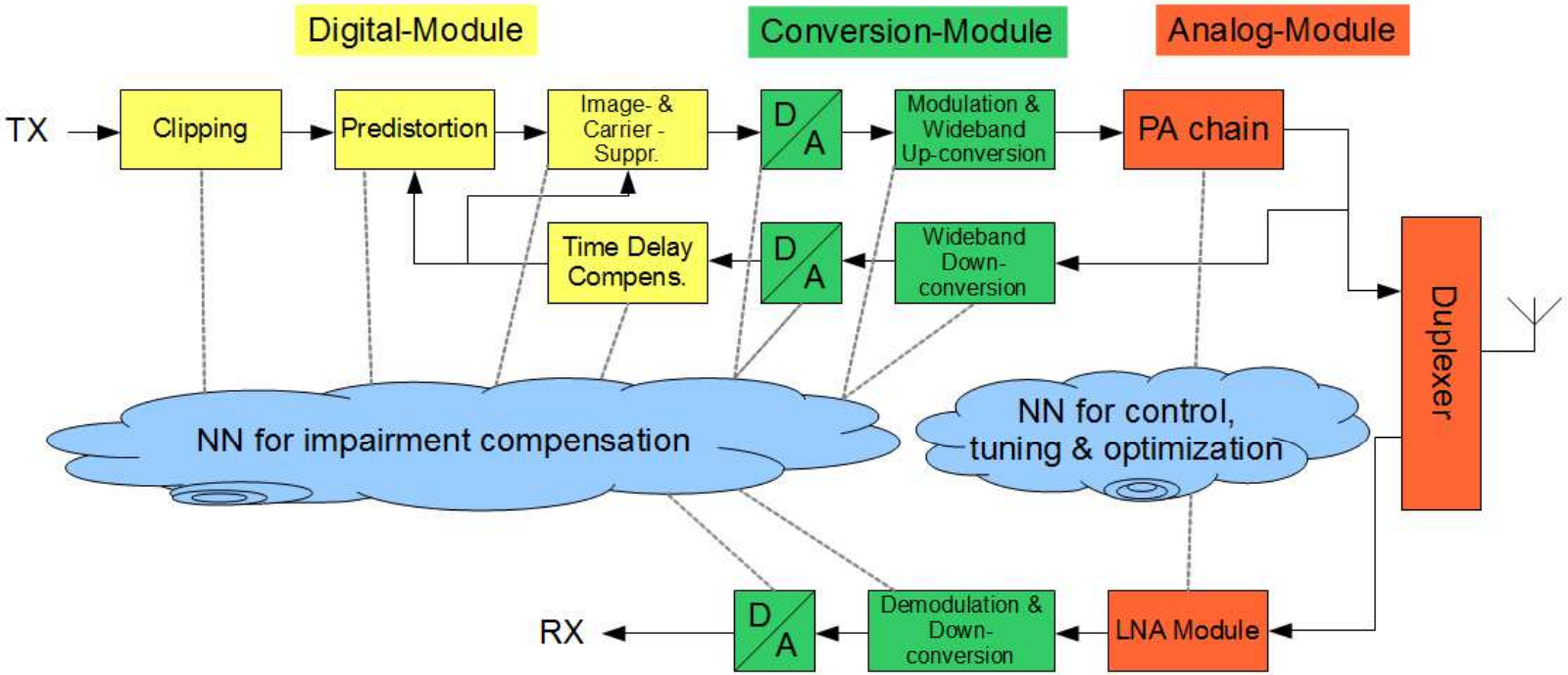


- Feedback to FhG-IAF
  ⇨ design improvement
- Data basis for intelligent amplifier control

Neural Networks in RF Transceivers

- Neural networks for compensation of stochastic and deterministic problems
- Solving problems without necessity of describing them mathematically or algorithmically
- Suitabillity for parallel processing (e.g. on FPGA)
  - –Enables high speed signal processing
- Applicable to different transceiver concepts and topologies
- Ability of self-learning and adaptation to different signals, scenarios and requirements

Applications for Neural Networks in RF Transceivers



RF impairment compensation

– IQ imbalance, pre-distortion, linearization,…

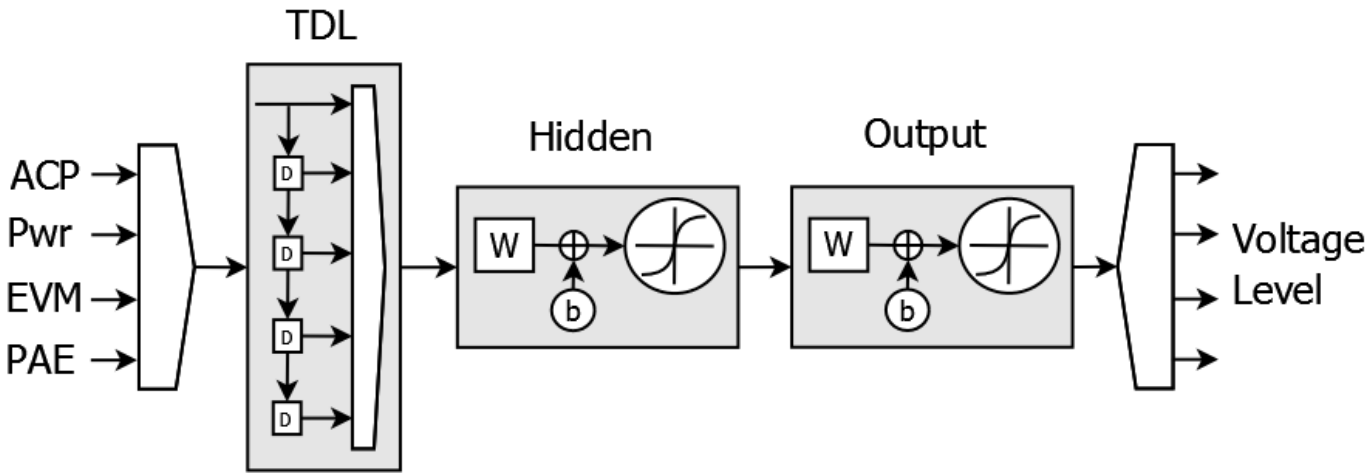
Control, tuning and optimization

– In digital signal processing (e.g. optimizing signal integrity)

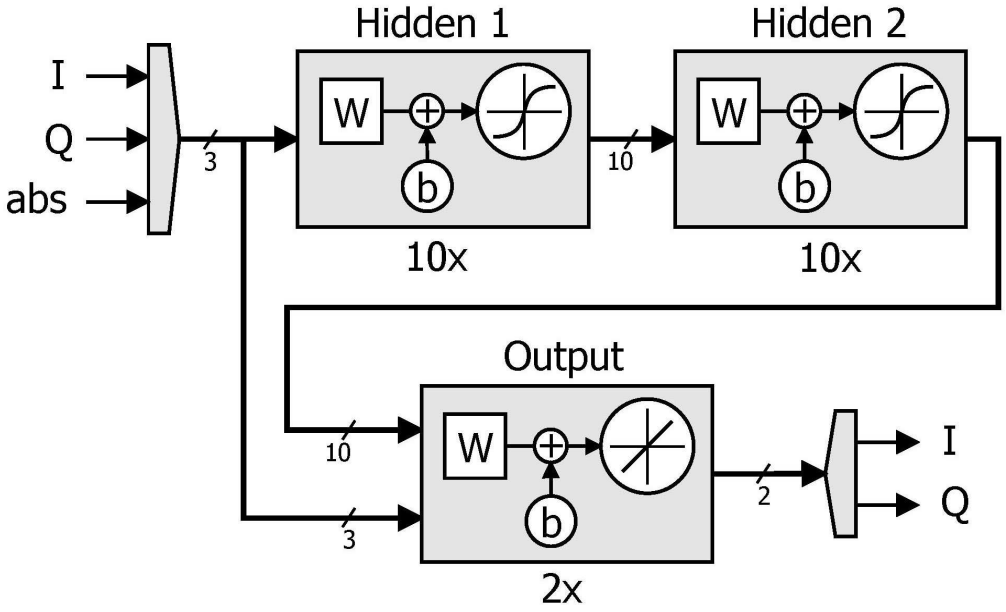
– In analog chain (e.g. optimizing PA efficiency by dynamic bias control)

Efficiency Optimization

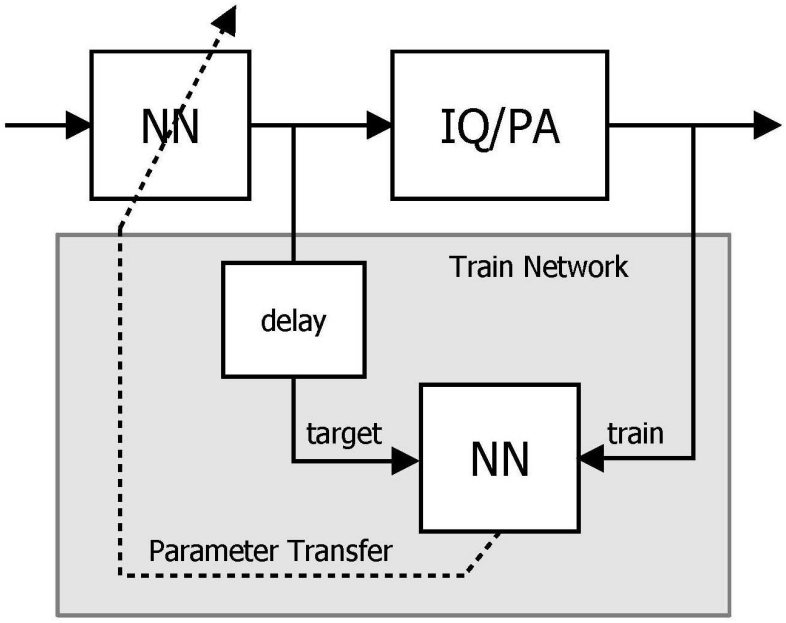
- NN trained on optimizing efficiency
- Benefits of NN in this application
  - Difficult analytical derivation of control algorithm for optimizing PA efficiency, e.g. due to hardware non-linearities
  - Ability to self-adapt to different signals and scenarios



Power Amplifier Linearization

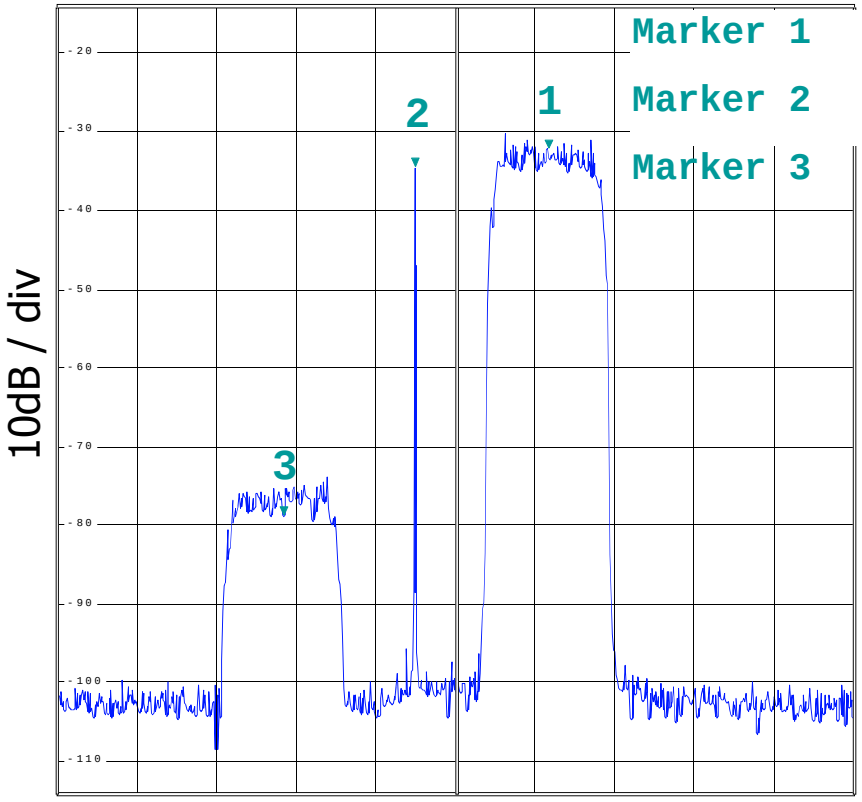


Neural network structure

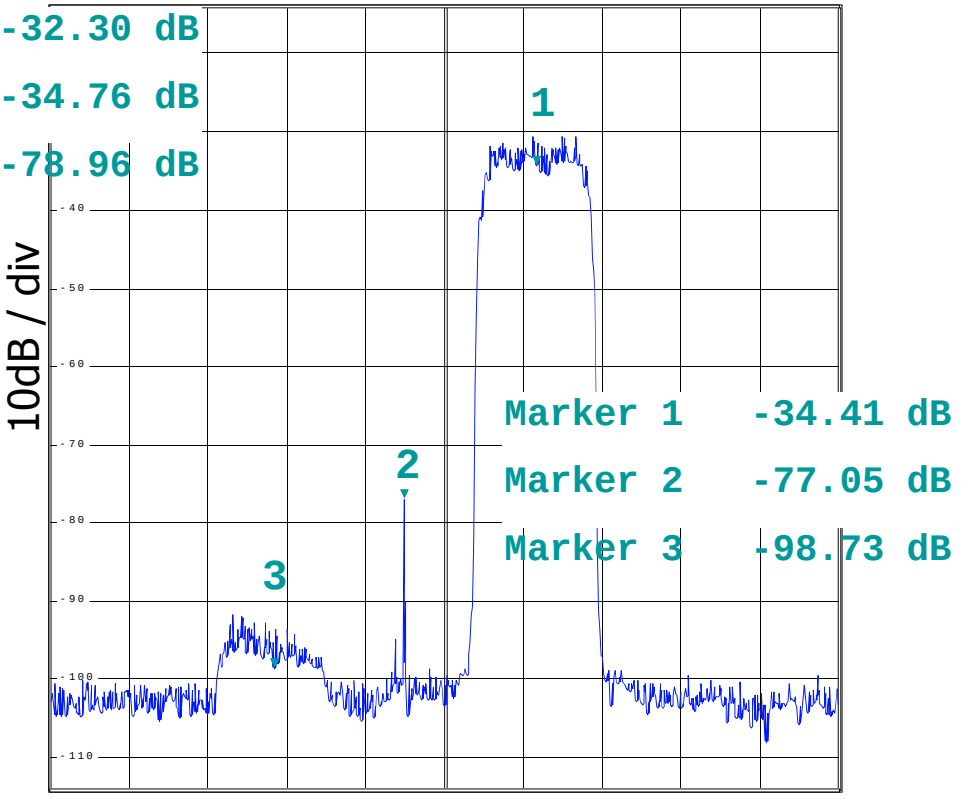


System architecture

Measurement Results for IQ Imbalance Mitigation

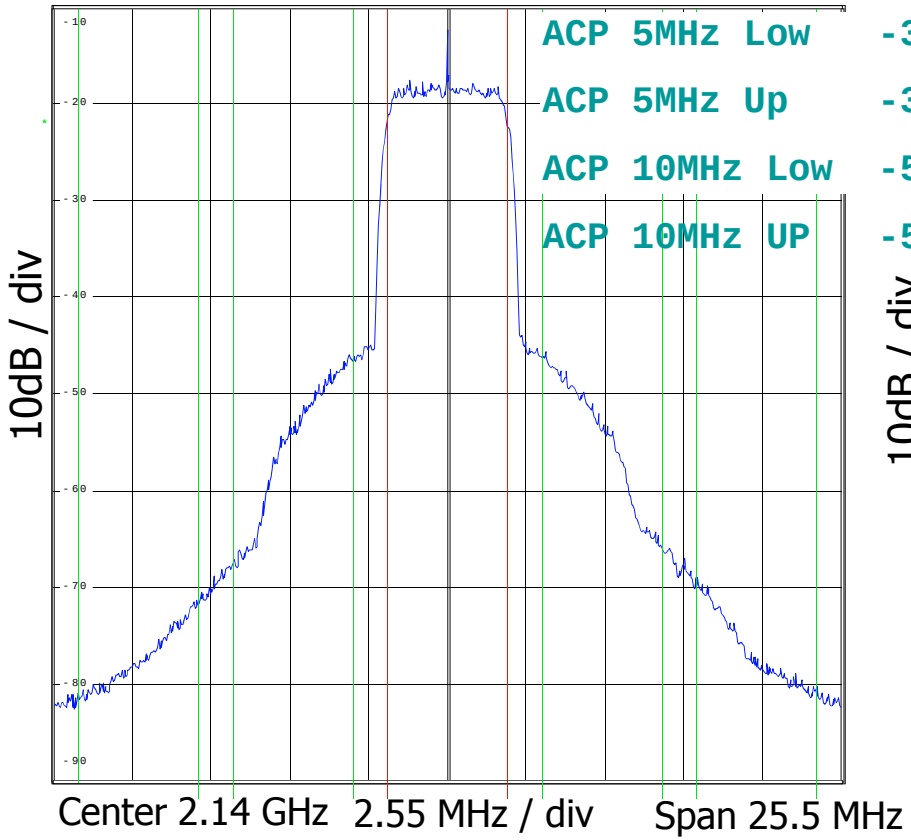


Output spectrum with IQ imbalance

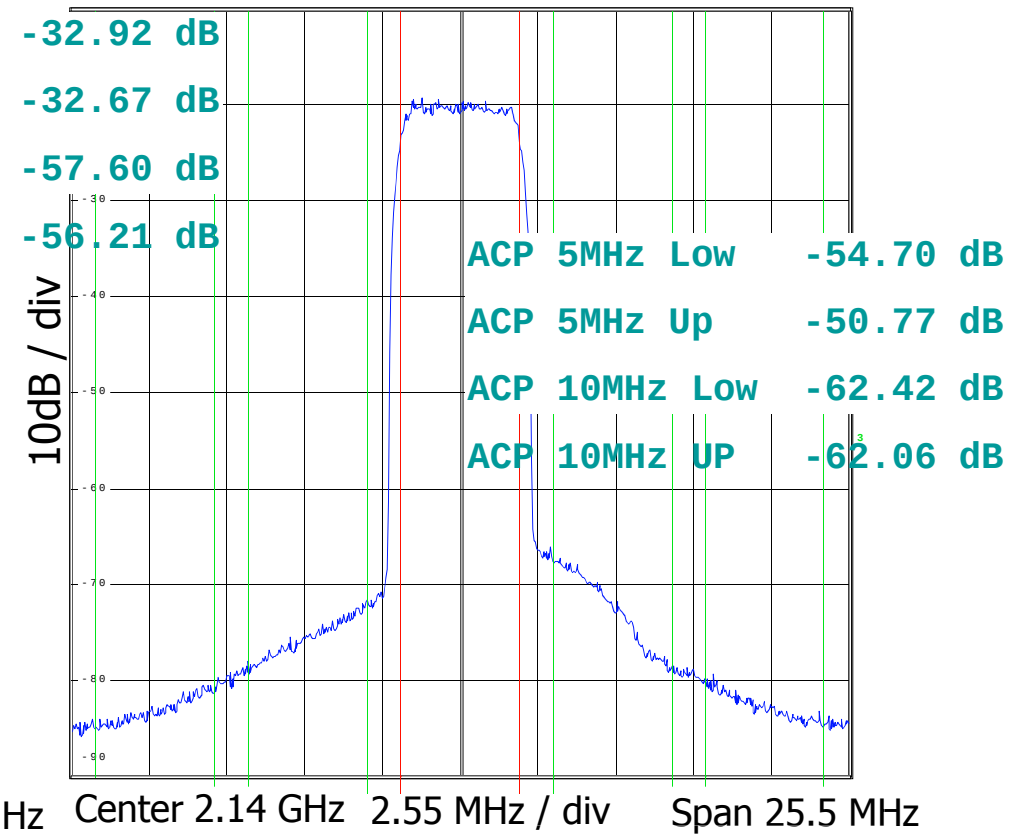


Output spectrum with NN applied

Measurement Results for PA Linearization



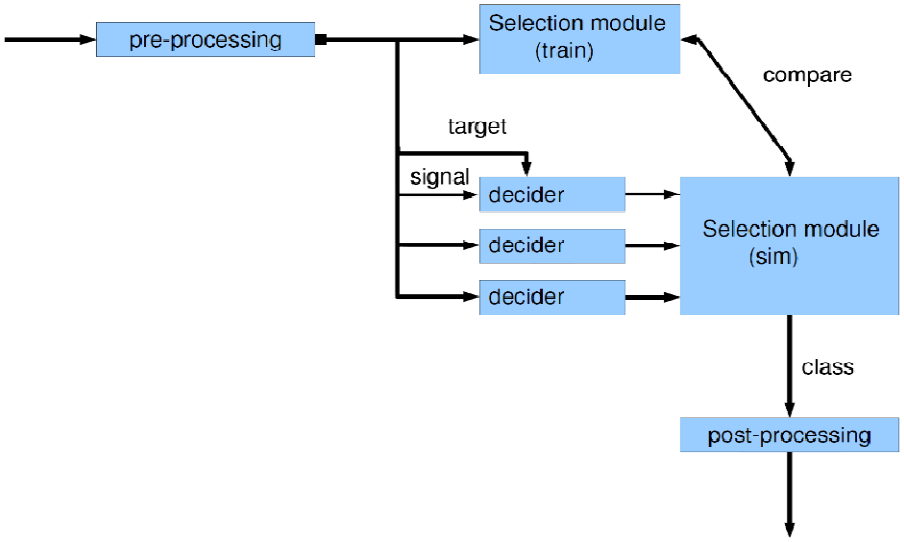
Non-linearized output spectrum



NN linearized output spectrum

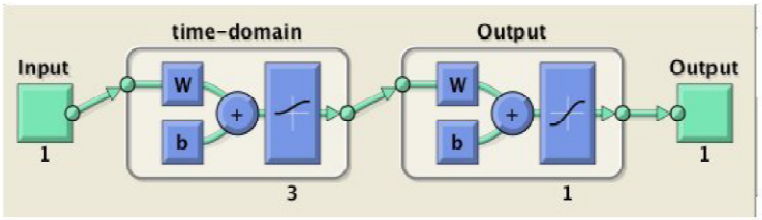
Classification of Signal Standards

- Detection of mobile radio standards in RF signals
- Pattern analysis of radio signal
- Benefits:
  - Adjusting standard specific parameters within transceiver (e.g. frequency)
  - No interaction between layers necessary

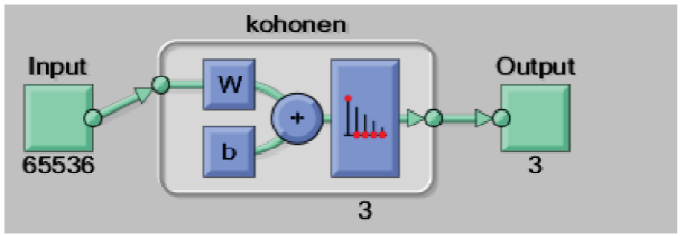


Classification of Signal Standards

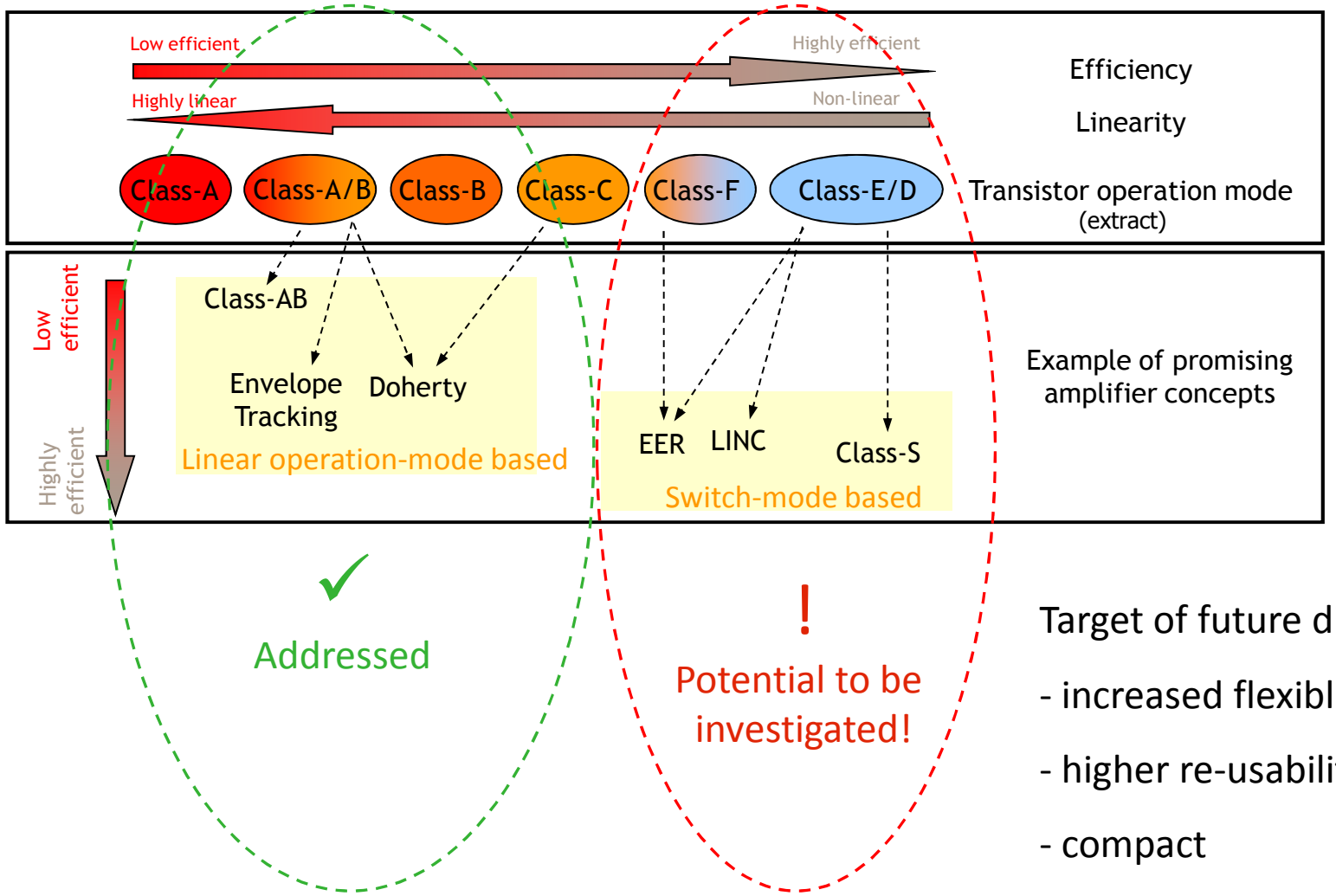
- System consists of Kohonen (SOM) and Pattern Networks
- Signal is quantized and modulated (DSM) at network input
  - Less neurons needed for serial processing
- First simulation results show, that accuracy must be enhanced



Pattern



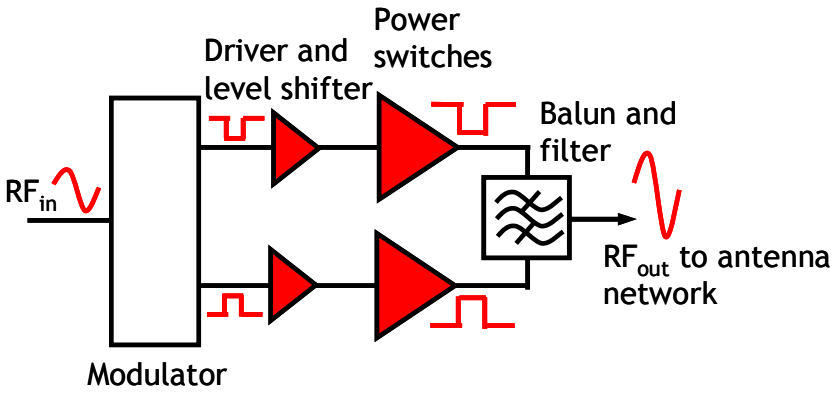
Amplifier Operation Modes

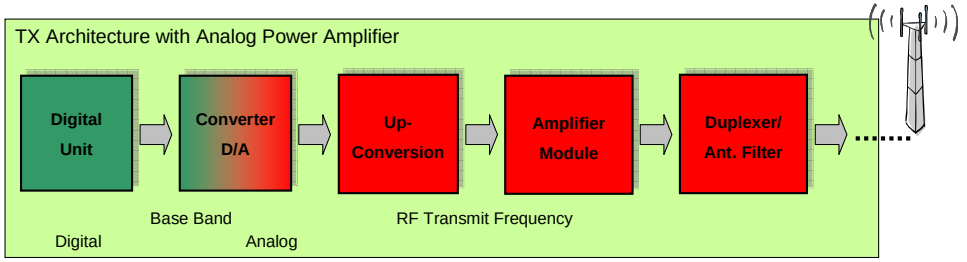


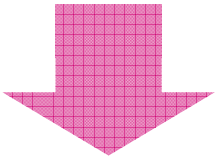
Target of future digital TX

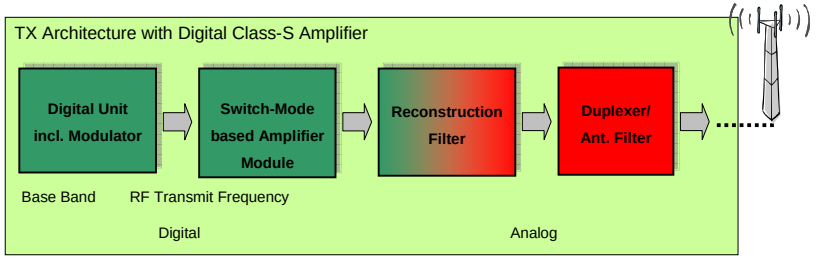
- increased flexiblity
- higher re-usability
- compact

SMPA – System Overview









Basic Idea Behind Class-S

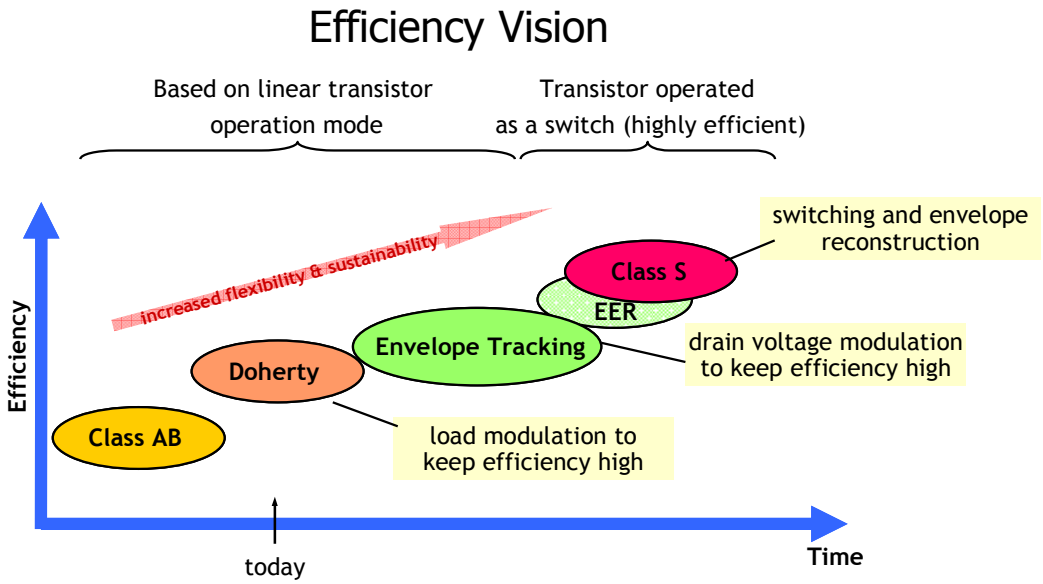
- Transistor operated in switch-mode operation (Potential for high energy efficiency, but highly non-linear)
- Modulator converts amplitude and phase modulated signal into appropriate control signal
- Output filter reconstructs wanted amplified transmit signal

⇨ **Vision: highly efficient and linear digital amplifier/transmitter**

SMPA – Research Questions

Expected Benefits by Class-S

- High potential energy efficiency due to switch-mode operation
- Attractive for wideband modulation schemes
- Increased flexibility, sustainability and compactness



Class-S Challenges

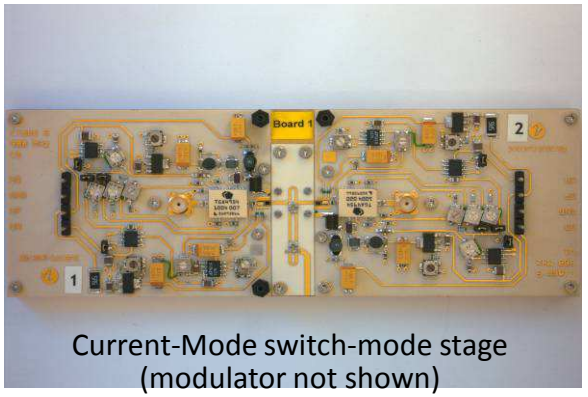
- Appropriate modulator providing high coding efficiency and high linearity
- Highly efficient switch-mode stages and drivers supporting required bandwidth and power
- Low loss and compact signal reconstruction filter, providing sufficient out-of-band termination

SMPA – Realization

Early Class-S RF Amplifier

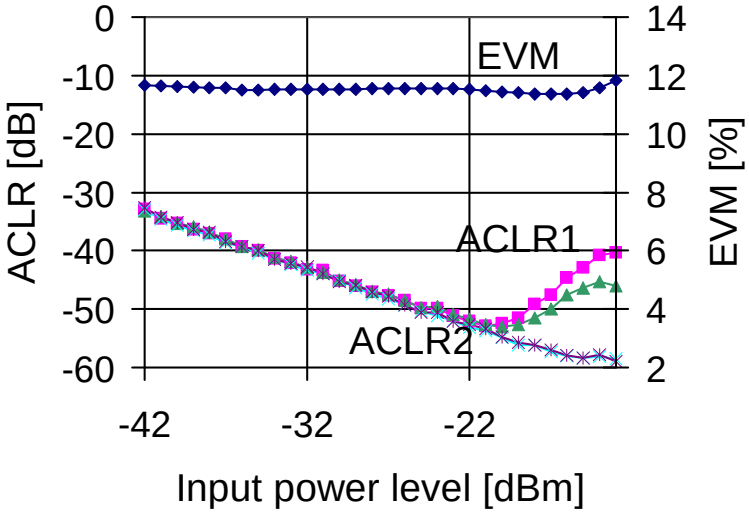
- 900 MHz carrier frequency (transmit band of filter)
- Good linearity (ACLR met over 8 dB dynamic range)
- Output power up to 17 dBm
- Energy efficiency still very low

⇨ Current research activities address power and efficiency improvement



Current-Mode switch-mode stage (modulator not shown)

GaN-MMIC's from FHG-IAF Freiburg



Summary

- Multi-band and multi-standard transceivers needed for future mobile communication systems
- Several applicable concepts investigated
- Dual-band transceivers designed
- Class-ABJ successfully tested as PA
- Neuronal networks applied
- SMPA demonstrated as promising new concept

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