RF-MEMS for frequency agile software defined RF Systems

Analog Software Radio Techniques for Multiband RF

Bell Labs
Europe

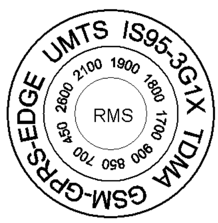
Bell Labs Europe

Dr. Georg Fischer
Consulting Member of Technical Staff
Lucent, Nuremberg

Lucent Technologies
Bell Labs Innovations

Contents

1) Why frequency agile RF Systems?
2) Relation to SDR
3) RF System design approach
4) RF MEMS
5) Demonstration activities
6) Summary



MOBILEonCHIP

TARGET
TOP AMPLIFIER RESEARCH GROUPS IN A EUROPEAN TEAM

GaN Elektronik

Bundesministerium für Bildung und Forschung

Research reported here was performed in the context of the network TARGET– "Top Amplifier Research Groups in a European Team" and supported by the Information Society Technologies Programme of the EU under contract IST-1-507893-NOE, www.target-net.org

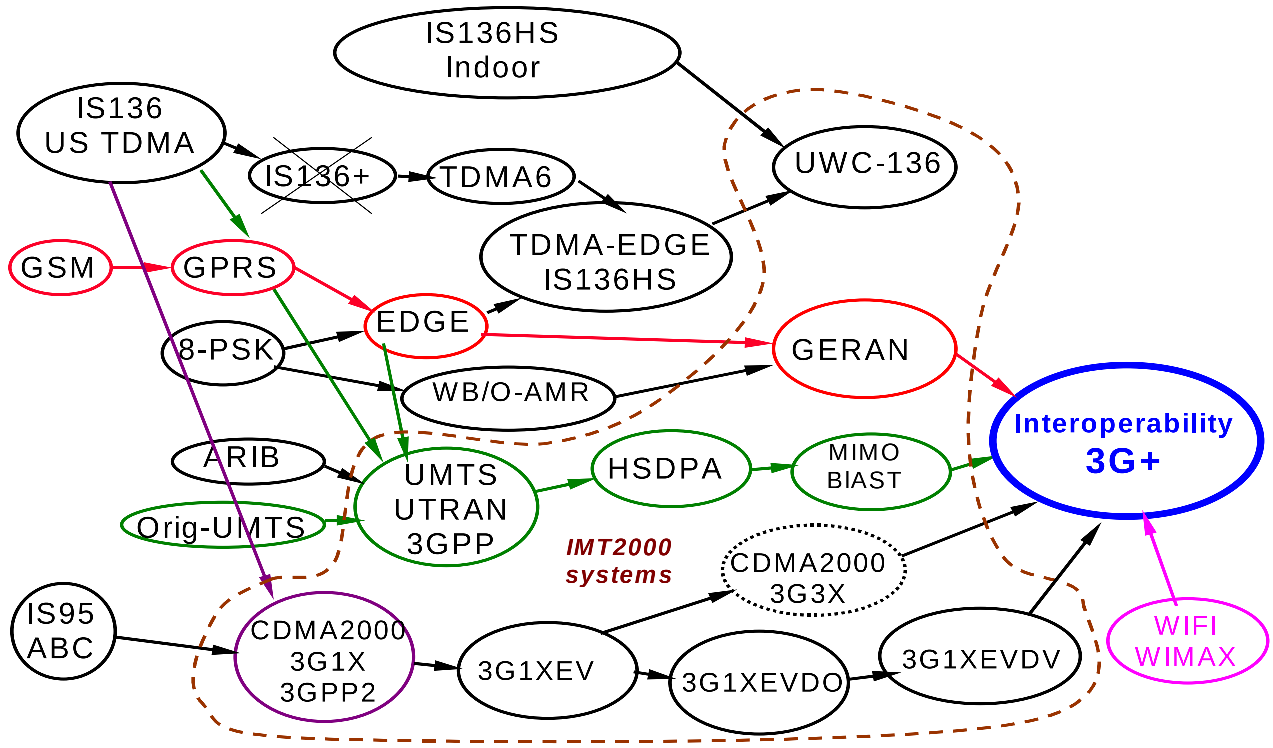
Part of this work is funded by the German Federal Ministry of Research and Education (BMBF).

Grants 01BU173 RMS, 01BU387 ERGAN and 01BU571 MARIO

The content of the publications is under the complete responsibility of the author.

1) Why frequency agile RF Systems?

Evolution of standards (air Interface protocols)



1) Why frequency agile RF Systems?

Mode=Band+Standard → **Standards**

Bands ↓

Band MHz	Note	Standard NMT	AMPS (analog)	IS136 TDMA (digital)	GSM / GPRS / EDGE	3GPP2, IS95, CDMA2000, 3G1XEV, CDMA-PAMR	3GPP UMTS FDD	Sub Chip Rate UMTS	3GPP UMTS TDD	WLAN WIFI WIMAX	Width
		10 or 30 kHz	30 kHz	30 kHz	200 kHz	1.25 MHz	5 MHz	1.25 or 2.5 MHz	5 MHz	1.25-20 MHz	MHz
300	Military										
410	PMR/PAMR	x				x		*future ?*			10
420	PMR/PAMR					x		*future ?*			10
450	PMR/PAMR (Former C-Net)	x			x	x		*future ?*			7.2
480	PMR/PAMR	x			x	x		*future ?*			7.2
700 alpha	Former TV				x	x					5
700 beta	"				x	x					10
750	New US										15
850	Cellular		x	x	x	x	x	*future ?*			25
870	PMR/PAMR										6
900	GSM	x			x		x	*future ?*			35
915	PMR/PAMR					x					6
1700	Korea - PCS					x					
1800	DCS				x		*future ?*	*future ?*			75
1900	PCS			x	x	x	x	*future ?*			60
2100	IMT-2000 FDD				x (UWC-136)	x	x	*future ?*			60
2100	IMT-2000 TDD							*future ?*	x	?	20
2300	US WCS										15
2400	ISM 11b/g									X	80
2500	MMDS									X	90
2600	New IMT2000?					x	x	10 MHz OFDM		X	180
3300	FWA									X	100
3500	FWA									X	200
5100-	UNII band									X	200
5400	WRC new									X	255
5700	UNII band									X	125

Problem: So far each „x“ a new product

➔ *More bands (22) than 3G+ standards (3)* ➔ *Multiband more important than Multistandard !*

1) Why frequency agile RF Systems?

Motivation factors

Lucent OneBTS

a) Basestation/handset variants

- Huge variety of products:
  - serving different markets
  - serving different frequency bands
  - serving different standards
- e.g. numbers of bands increasing beyond 4 (Quattroband)

b) Spectrum deliberalization

- New frequency bands being opened up
- Design cycle to introduce appropriate hardware?
- Cognitive radios seek for unused spectrum and use it according agreed policies

Already some sort of ambient intelligence

c) Future end to end reconfigurable networks

- See EU project E2R

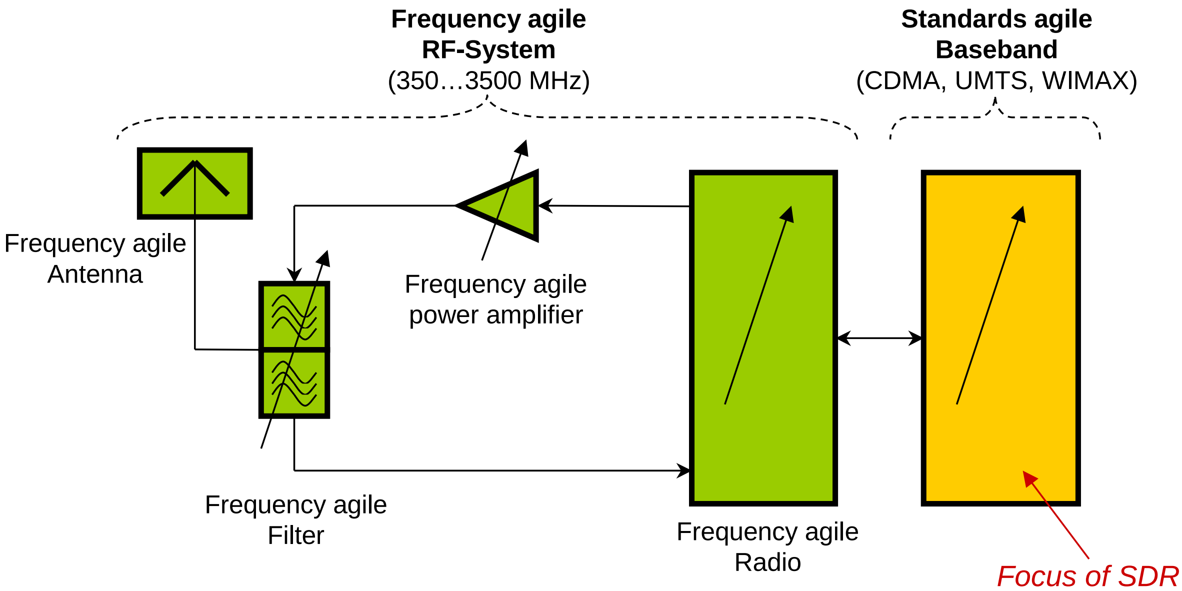
d) Network migration strategies

- Transition phases between standard generations

2) Relation to SDR

What is a frequency agile RF System?

- All RF units of RF system are reconfigurable, not only the radio!
- Allows remote setting of frequency band
- No need to exchange part of the hardware, when changing band

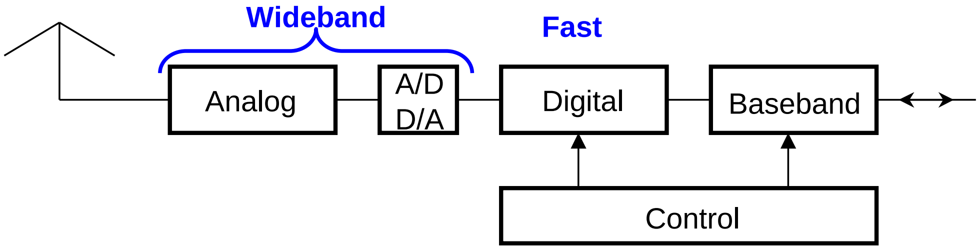


2) Relation to SDR

A refined view at SDR

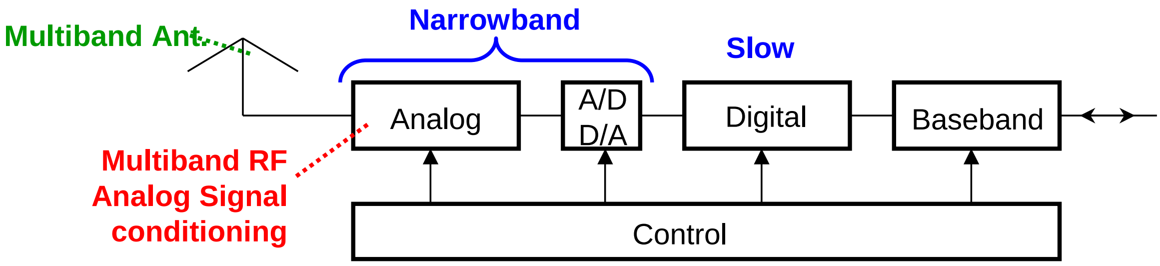
SDR - classical

- Only characteristics of digital and baseband part defined by software
- Analog part stays fixed, only single band
- No reduction of information in analog part



SDR - refined - With Frequency Agility

- Characteristics of analog part and conversion also defined by software



2) Relation to SDR

Analog Signal Conditioning to knock down information

Filtering=bandwidth limitation ← **Let's use RF-MEMS**

- Coarse filtering analog domain, precise filtering digital domain
- Reduces sampling bandwidth → less data to process
- Eliminates/Attenuates blockers → less SFDR sufficient for converters
- Limits noise bandwidth

AGC=Gain Ranging

- Adjust gain to signal of interest
- Reduced dynamic range → less resolution sufficient for converters
- Less bits → less data to process

Find the right balance in doing a signal processing job analog or digital !

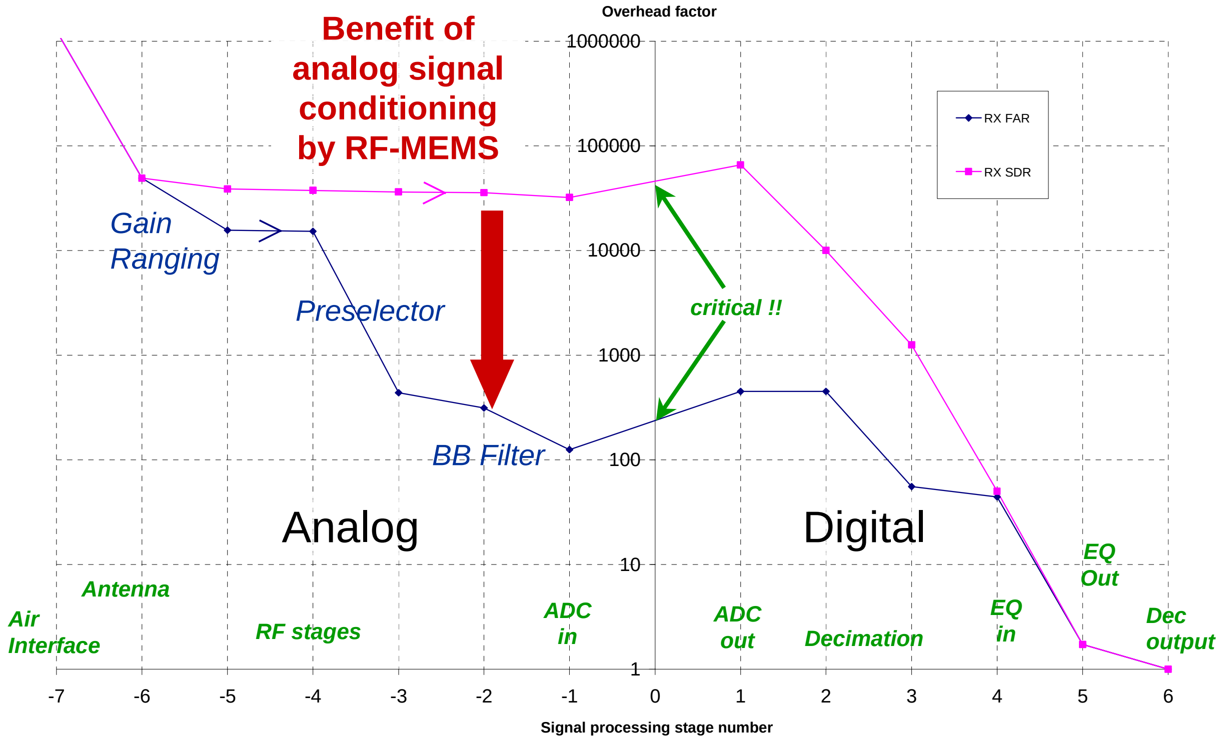
2) Relation to SDR

New Method for analyzing complexity of architecture

- Wish: One metric for analog and digital !
- Def.: Overhead factor
  - Amount of data relative to net data stream
  - Defined for each signal processing stage
- Net Data stream: Typical 12.2 kbit/s for voice
- Calculations:
  - Analog domain: Use Shannon
    B=bandwidth, SNR=Signal-to-Noise-ratio
    $$C_{Analog} = B \cdot ld\left(1 + \frac{S}{N}\right) = B \cdot ld\left(1 + 10^{SNR_{dB}/10}\right)$$
  - Digital domain:
    N=resolution, r=clock frequency
    $$C_{Digital} = N \cdot r$$
  - Overhead factor:
    $$O_i = \frac{C_i}{12.2\, kbit/s}$$
- By definition
  - Decoders output / Coders input: $O_i = 1$
  - air interface: $O_i = \infty$
- Method applicable for TX and RX

2) Relation to SDR

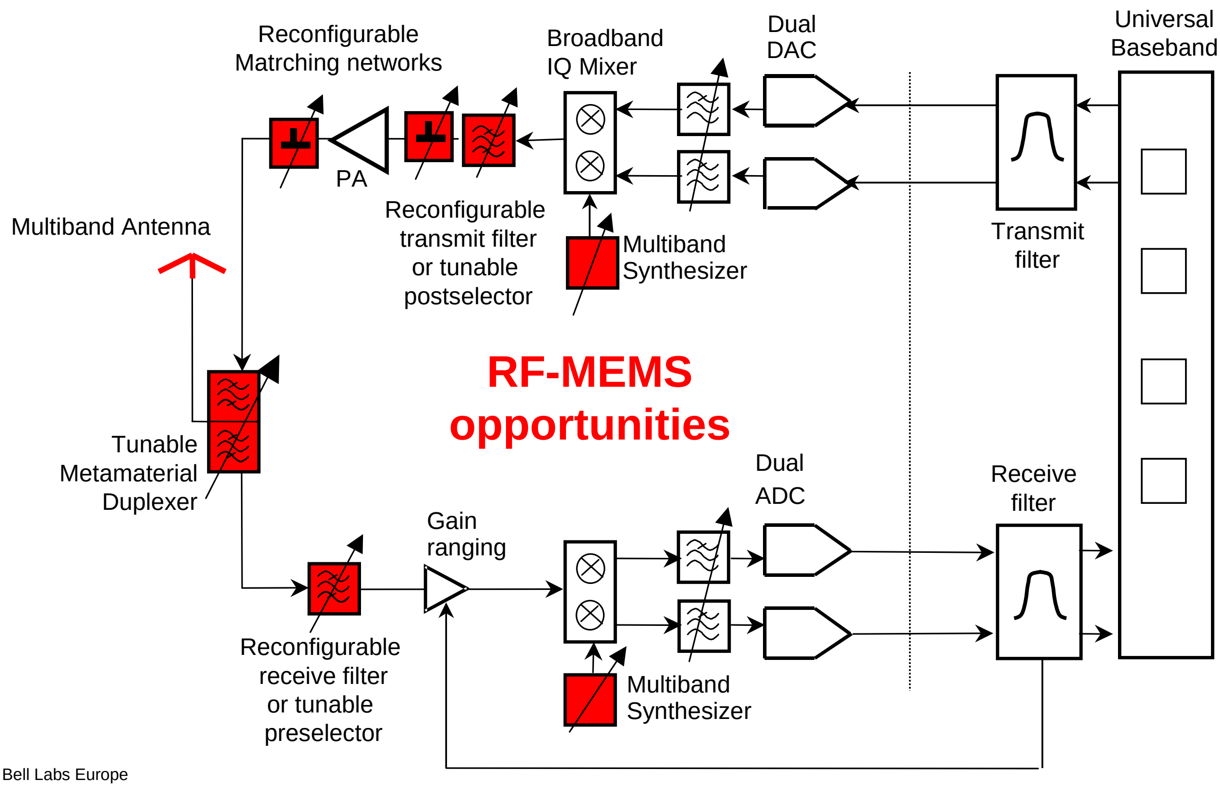
Graph showing overhead factor



→ ***Factor 400** (80000/200) **reduction in complexity!***

3) RF System design approach

Opportunities to use RF-MEMS

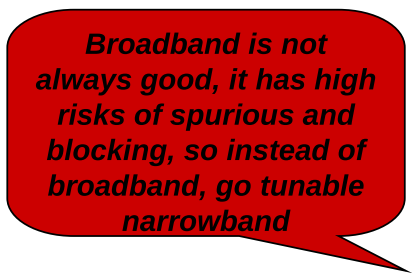


3) RF System design approach

Duplex problem

Challenge
- Transmitter and Receiver have to be operated in parallel
- A TX/RX switch as with classical SDR cannot be used
- Huge Dynamic range between TX and RX (e.g. 120 dB)
- Risk that receiver is desensitized by wideband noise from own transmitter

Classical solution
- Large form factor duplexer
- Based on coaxial resonators, Q=5000
- High costs
- How to make this tunable over multiple octaves?



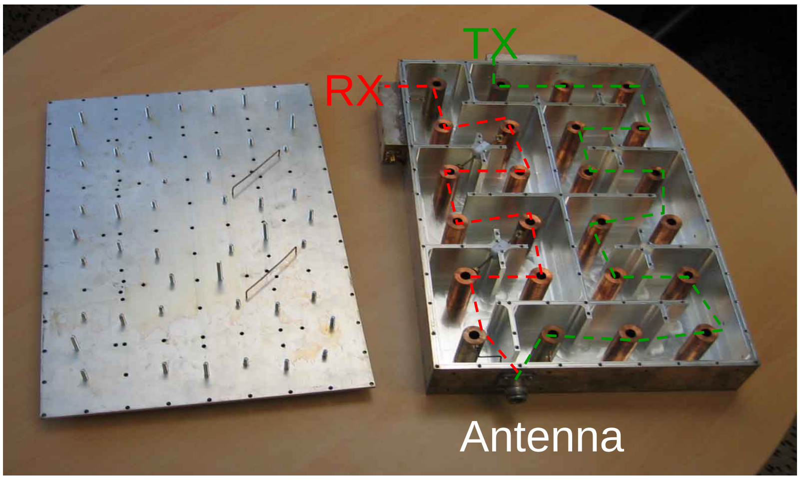
Alternative approach
- Distributed filtering
- Keep bandwidth small at every signal stage
- Balance between coarse analog and precise digital filtering
- Do more filtering at low power RF, to relax duplexer requirements at high power
- Coarse analog filtering supported by RF-MEMS

3) RF System design approach

Duplex problem

Classical solution

- Coaxial resonators
- Fixed characteristics
- Only a few % tuneable



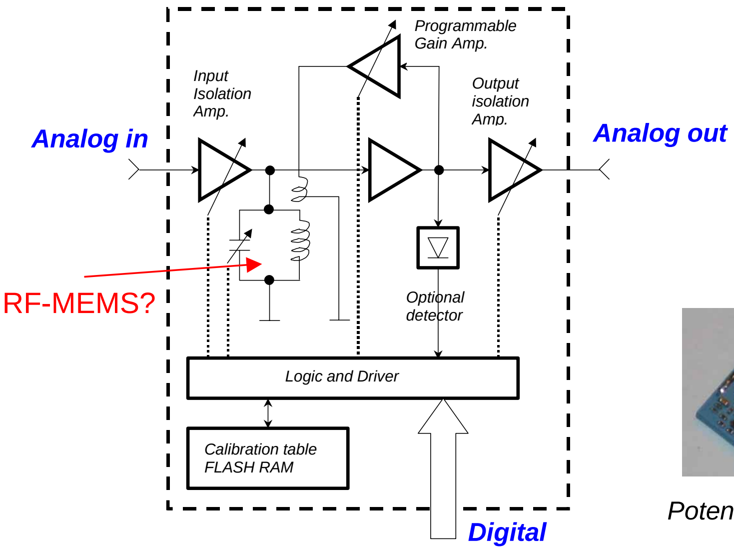
Stepper motor tuning

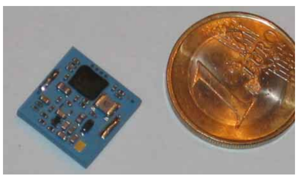
Duplex filter

- 24cm x 36cm x 5cm
- Q=5000, silver plated
- 14 TX, 10 RX resonators
- High costs, high weight

3) RF System design approach

Distributed filtering (preselector, postselector)



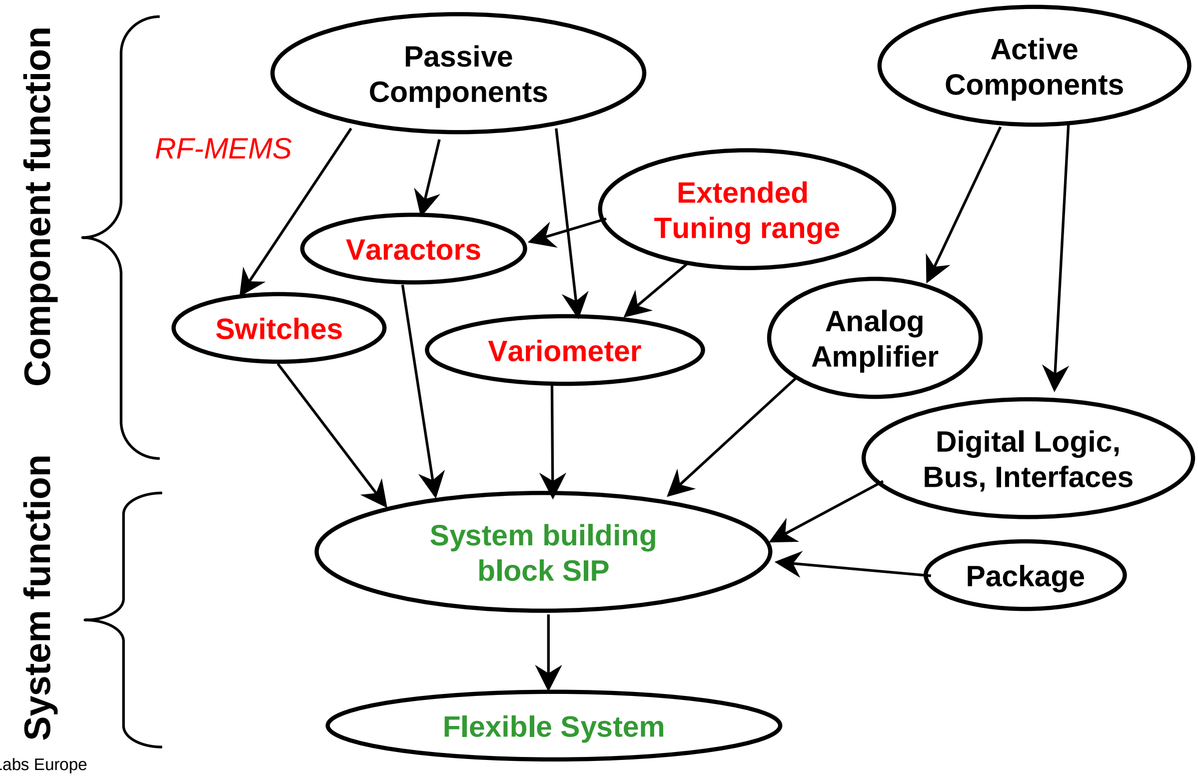


Potential Realization in LTCC

- Reconfiguration of analog path through a digital Interface
  - Analog properties set by software *(new understanding of SDR)*
- Encapsulation concept
  - Isolation amps *(No detuning due to outer impedance variations)*
  - Buried resonant structure *(No detuning due to electromagnetic coupling)*

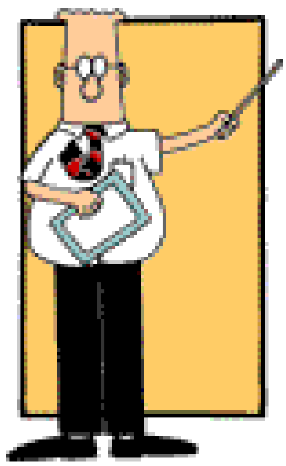
3) RF System design approach

RFB (Radio Function Block) realized as a SIP (System in Package)



4) RF-MEMS

Likes, to dos, don't cares, needs…



Likes
- Separation of DC control and RF-path → reduces crosstalk
- No Bias-Ts! → nice with complex topology of reconfigurable RF circuits
- Inherently linear on RF-path (not an active device)
- Near ideal switch (Low loss, high isolation)

To do
- Increase power handling capability (10....20W ?)
- Package shouldn't degrade superior RF performance at die level
- Step up from component to system building block function!
- Combine RF-MEMS with active devices and logic

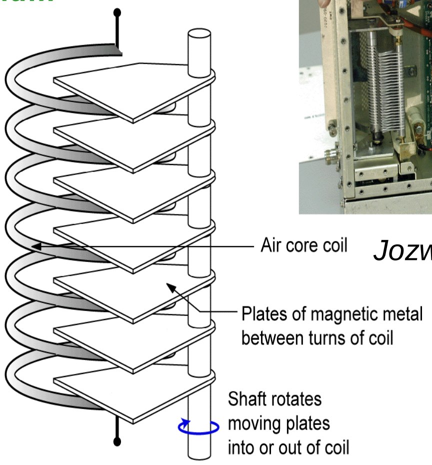
Don't care about
- Actuation voltage / Actuation power
- Number of switching cycles (Only Reconfiguration)
- Dynamics/switching speed (Only Reconfiguration)

Devices needed
- RF Switch matrices e.g. SP4T (resistive switch, not capacitive)
- Varactors=tunable C, together with switchable bank of fixed cap
- Variometers=tunable L, together with switchable bank of fixed inductors
- Pre-/Postselector=tunable C+tunable L + switches combined

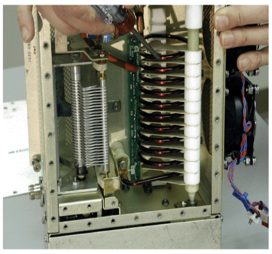
4) RF-MEMS

MEMS inductor, variometer activities

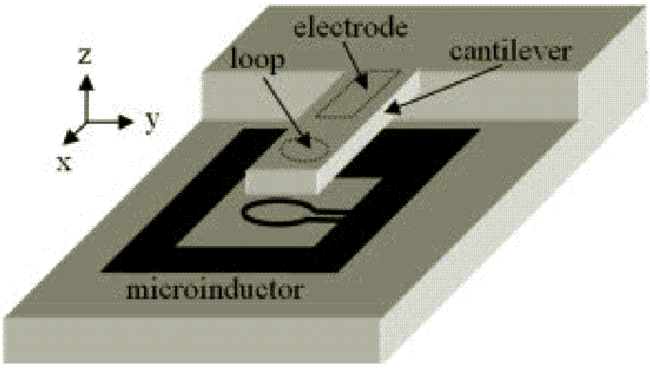
old…



Magnetically Variable Coil



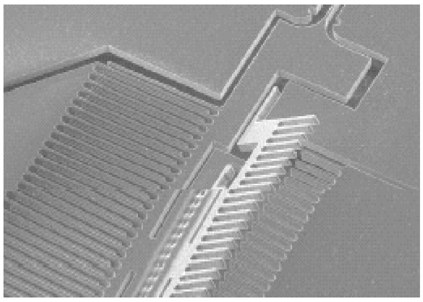
Jozwiak



Tassetti, ESIEE France

new…

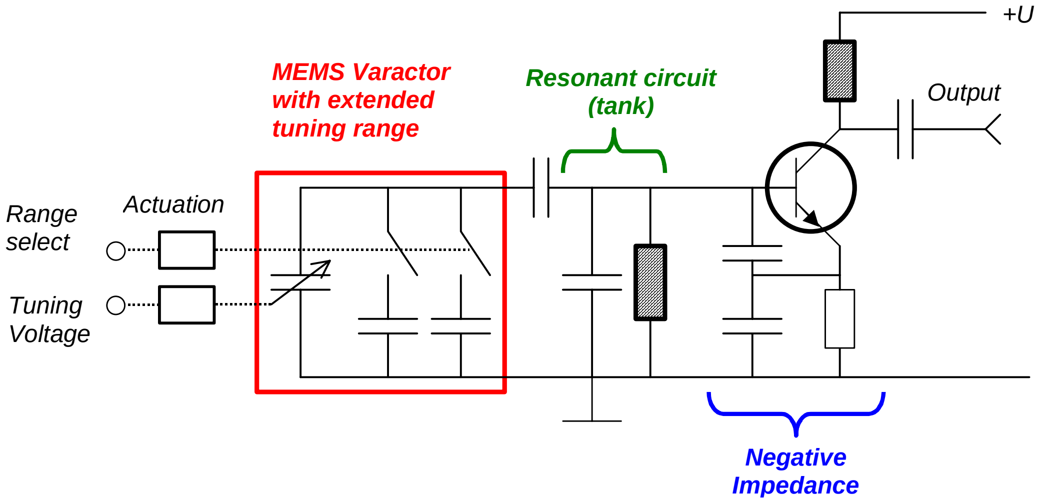
Hector de Los Santos, NanoMEMS LLC



4) RF-MEMS

for a wide tuning VCO

- Wide tuning MEMS varactor
- Great Frequency ratio
- No Bias-T like with varactor diode, control isolated from RF
- Lowpass characteristic of control loop by mechanical damping of MEMS varactor



4) RF-MEMS

for a tunable duplex filter

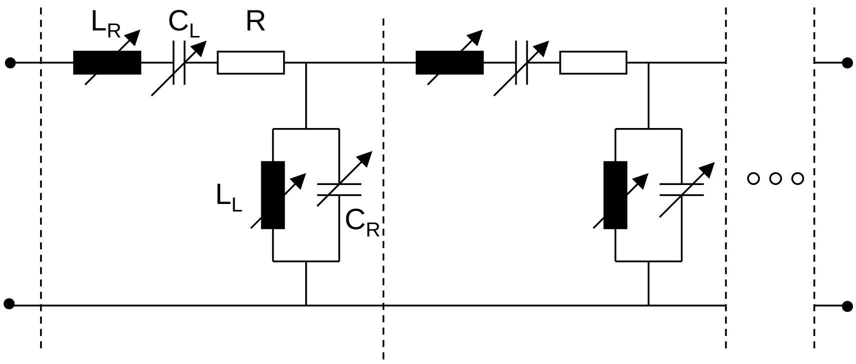
New approach - Metamaterial duplexer

- Use of composite left and right handed structures
- Use of zero order resonance
- With zero order resonance losses in series tuning elements (R) don't degrade Q

$\varepsilon_r < 0, \quad \mu_r < 0$

$n<0$

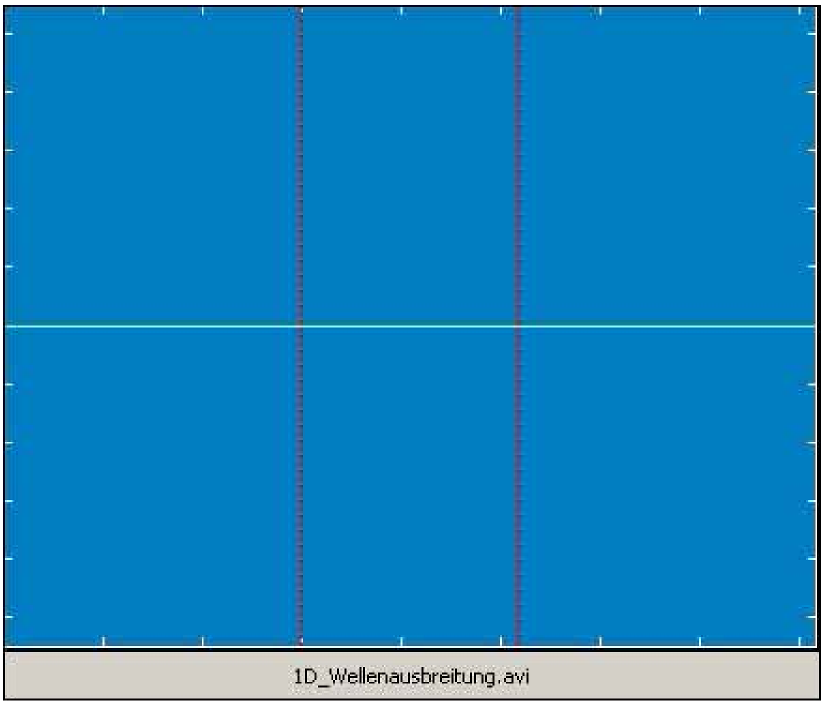
$V_{ph}<o, \quad V_{gr} >0$



Equivalent circuit unit cell of Composite Left Right handed transmission line CRLT

4) RF-MEMS

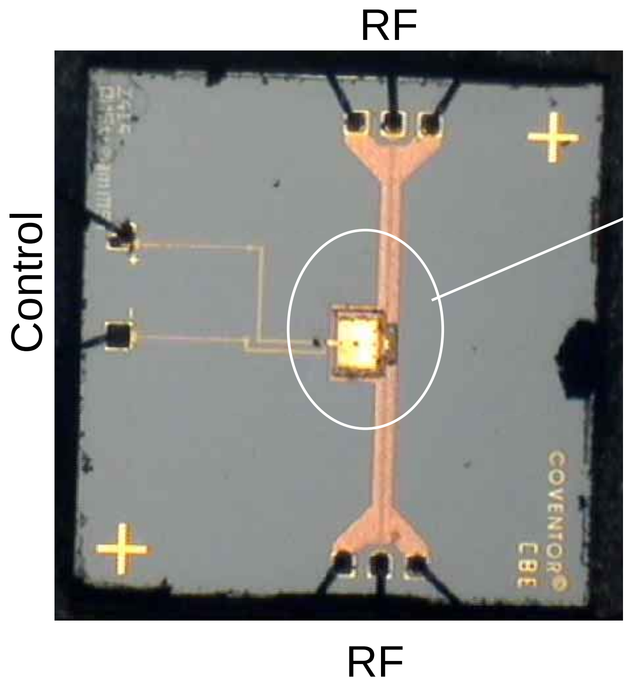
for a tunable duplex filter

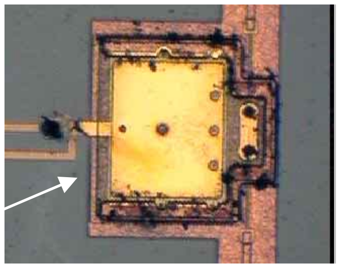


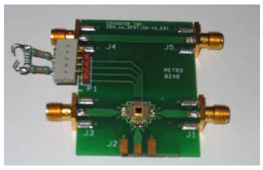
Source, Department of RF, Prof. Schmidt, UNI Erlangen, Germany

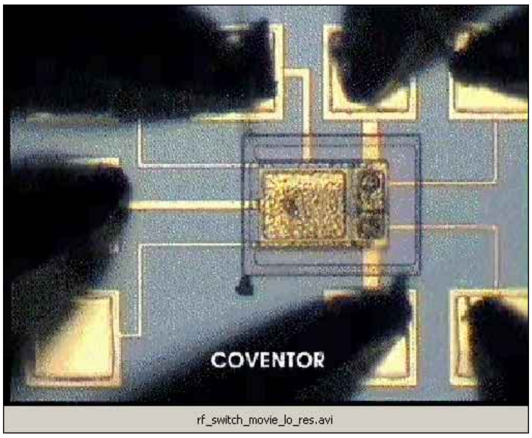
5) Demonstration activities

MEMS Switch



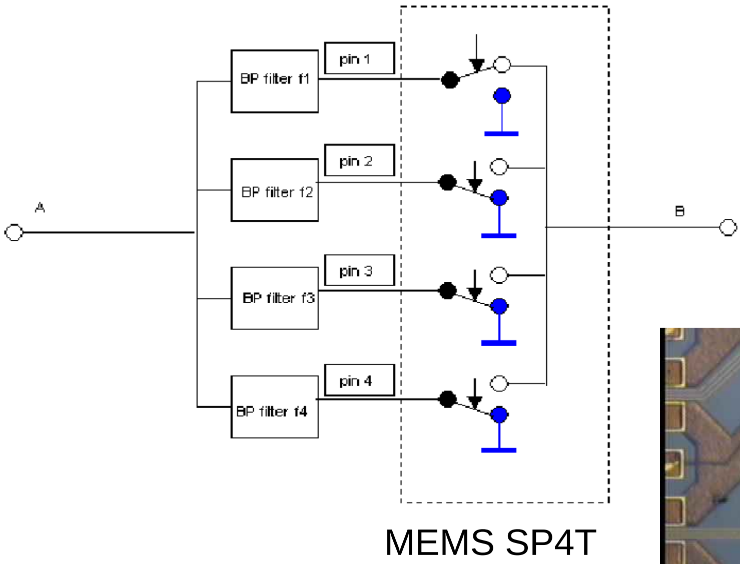


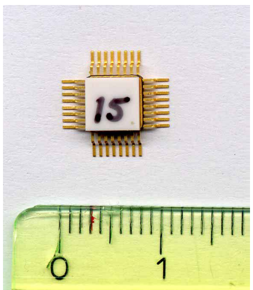


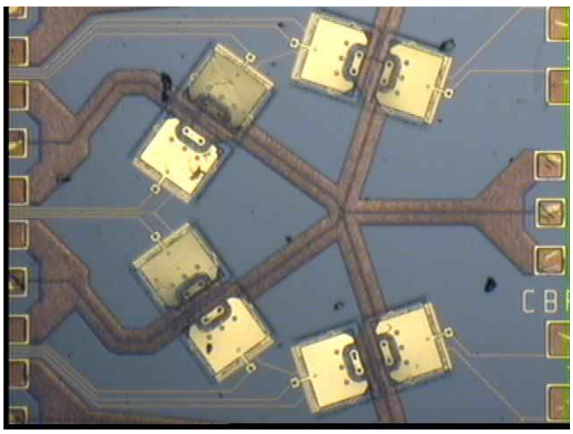


5) Demonstration activities

MEMS switch matrix





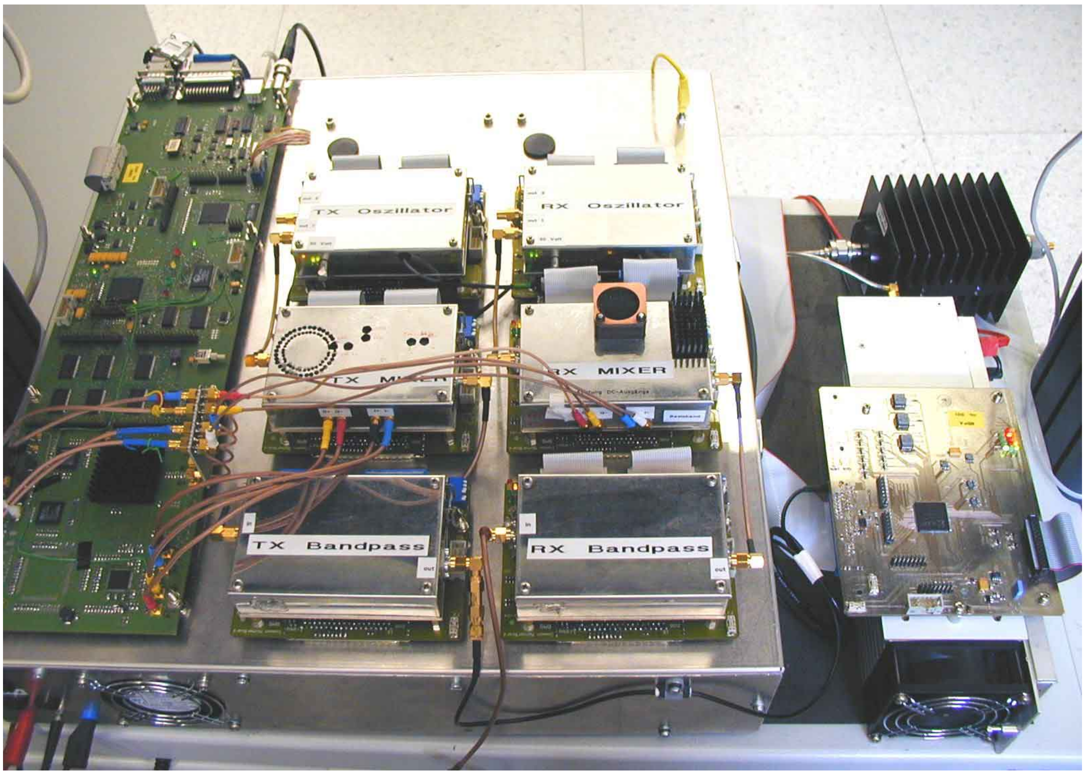


- Unselected filters enhance stopband attenuation

Coventor

5) Demonstration activities

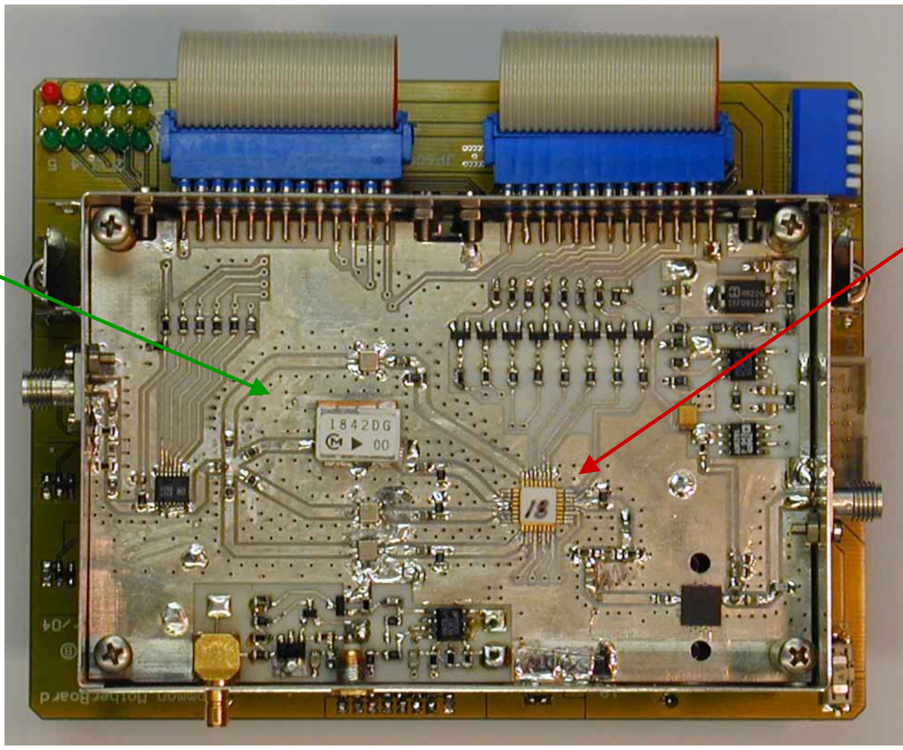
Frequency agile basestation



5) Demonstration activities

RXBP - Receive Bandpass

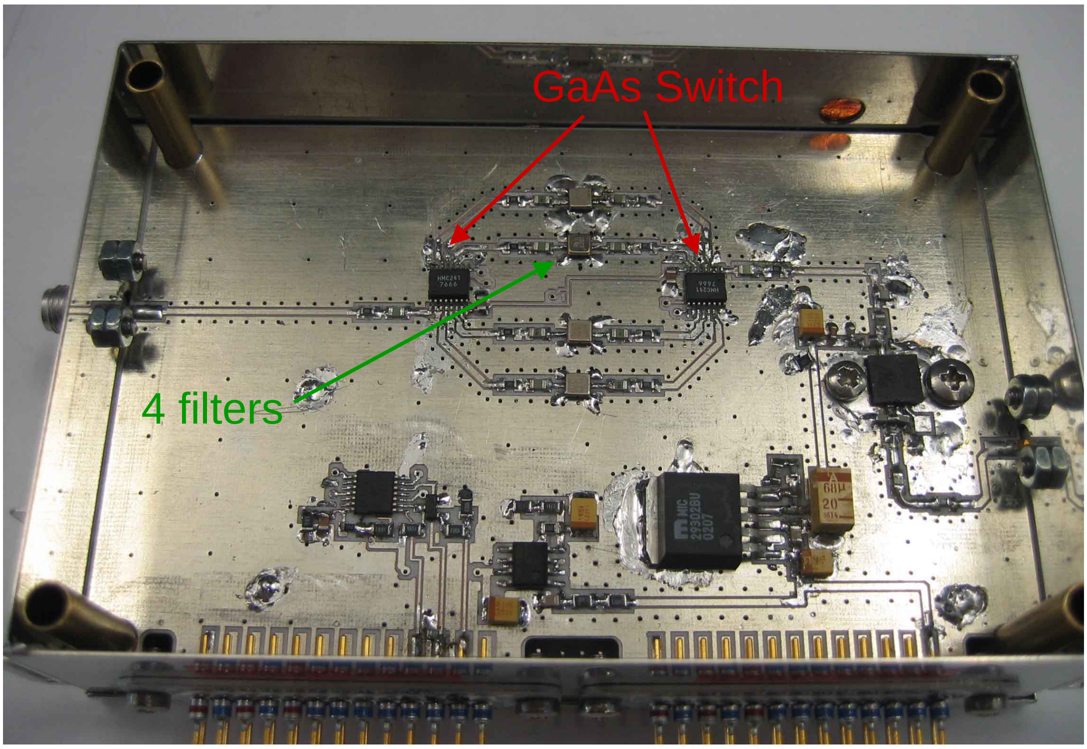
4 filters



RF-MEMS Switch Matrix

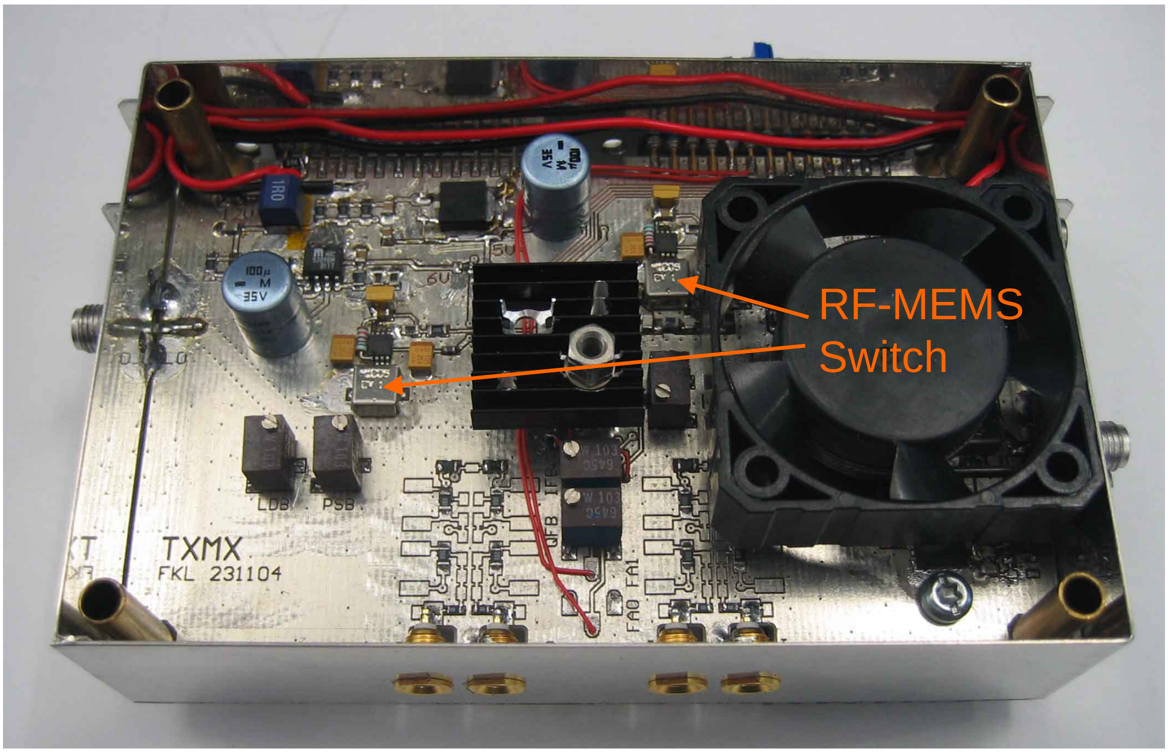
5) Demonstration activities

TXBP - Transmit Bandpass



5) Demonstration activities

TXMX - Transmit Mixer (top side)



6) Summary

- Frequency agile RF-System
  - Not only the radio, but also the antenna, the duplex filter and the PA has to be reconfigurable
- Ambient intelligence
  - Cognitive radio, seeking for free spectrum to be used
  - Adaptation to various bands and standards
- RF-MEMS
  - A Renaissance of Analog
  - Well suited for signal conditioning in analog
  - Key to distributed filter approach (pre-/postselector)
  - Beneficial characteristics from system view
  - Attractive for tunable metamaterial
- RF-MEMS to dos:
  - Increase power handling capability
  - Variometers (tunable L) needed
  - Combine different MEMS elements to form a system function
  - Combination RF-MEMS with active devices
- Demonstration
  - Benefits of RF-MEMS
  - Frequency agile basestation

A frequency agile basestation has been demonstrated based on RF-MEMS