High Performance RF in Wireless Infrastructures

Domine M.W. Leenaerts

domine.leenaerts@nxp.com

NXP Semiconductors, The Netherlands

TU/e Technische Universiteit Eindhoven University of Technology

Content

- **Wireless infrastructures**
  - **State-of-the-art**
  - **Need for (further) integration**
- **(Re) Quest for High Performance RF**
  - **Technology**
  - **Design**
- **Concluding remarks**

Wireless communication

cellular base station

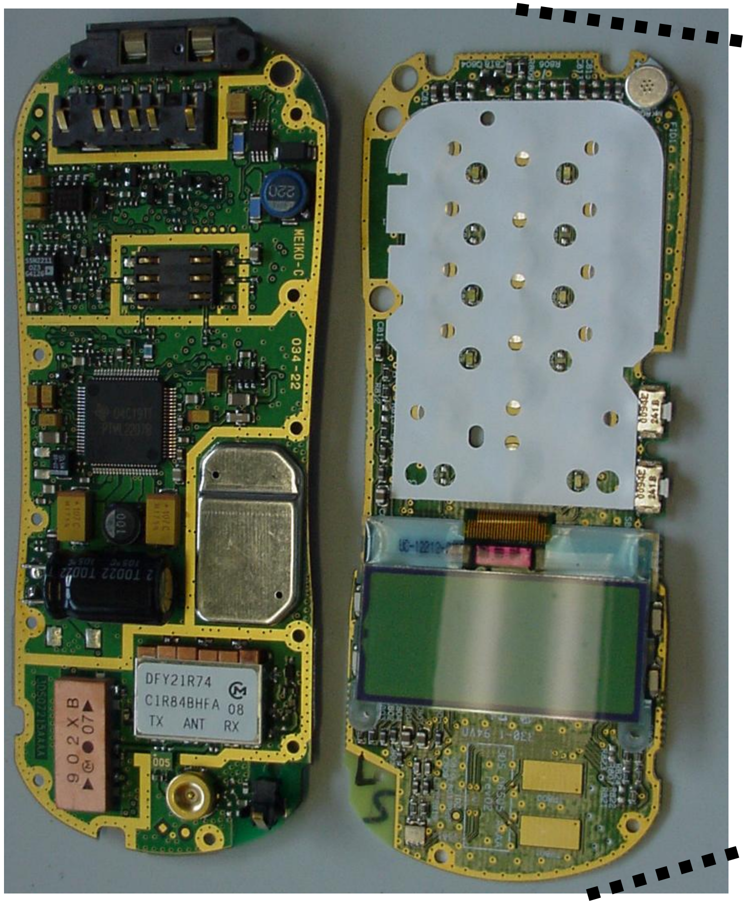
cellular handheld

Wireless infrastructures

Ka/Ku band satellite

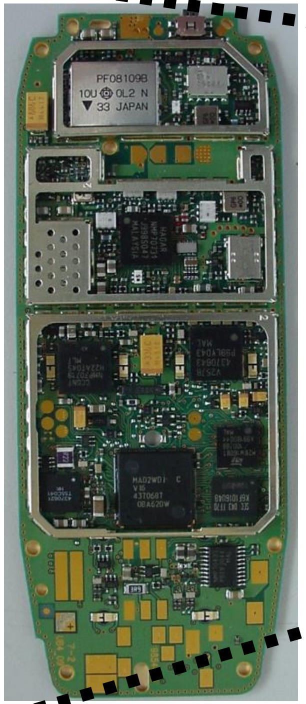
Trend in cellular mobile handset

1995



GSM900

2000

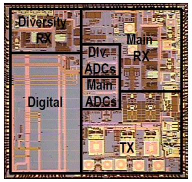


GSM900/1800/1900

2007

Quad EDGE
Triple WCDMA

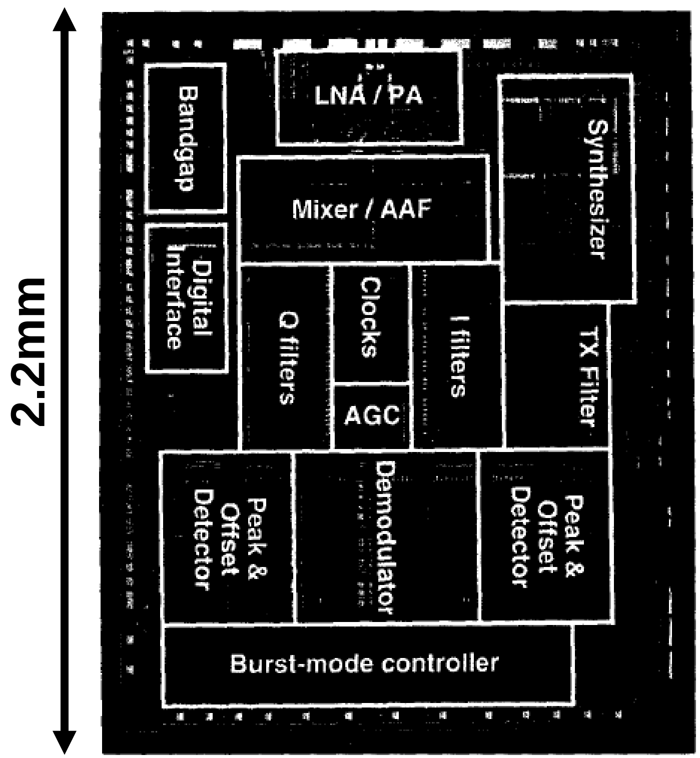
2009



3.9G

Thanks to impressive integration

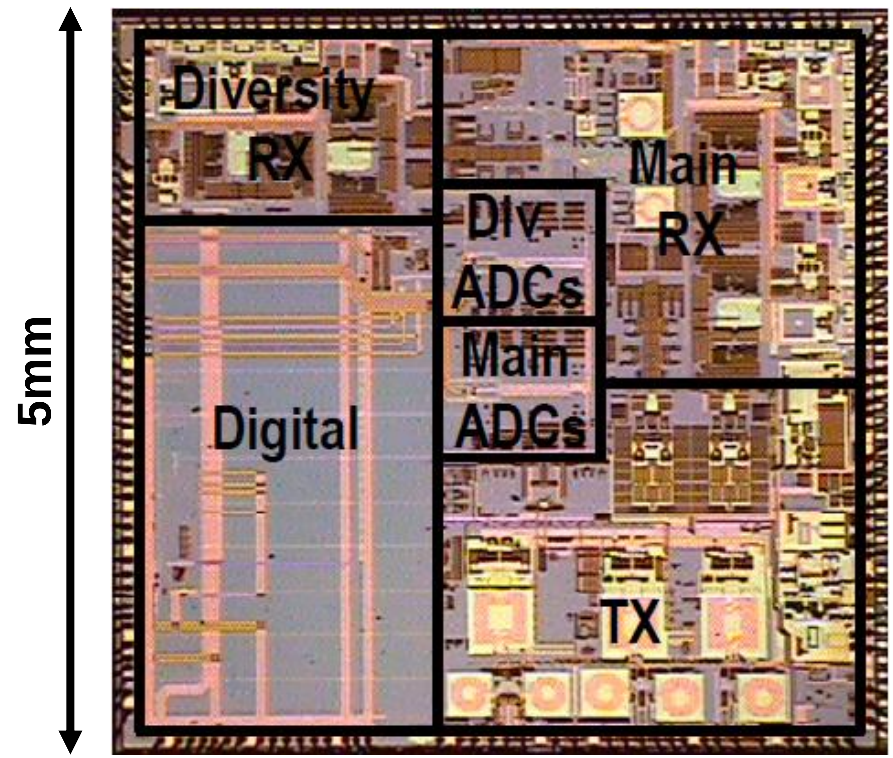
ISSCC1999



GSM900 TRx

0.25μm CMOS

ISSCC2009



WCDMA/HSDPA/HSUPA/EGPRS TRx

0.13μm CMOS

State-of-the-art cellular handheld

- **Typical consumer market product**
  - Cost is key
  - Integration of functionality in Si-based technology
  - CMOS scaling lead to RF capability of devices
  - SoC solutions became possible

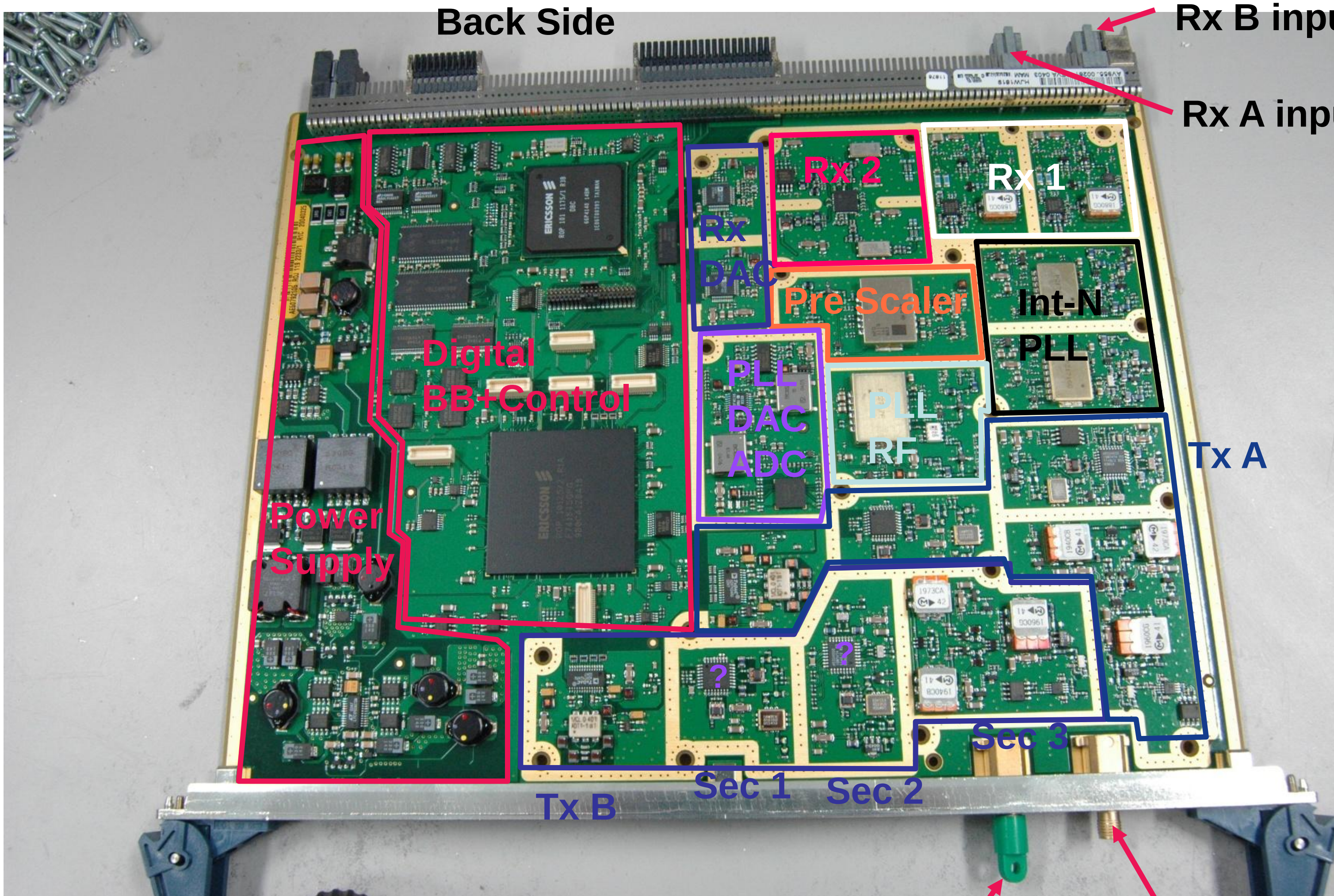
Let’s look at cellular base station

Tower + cabinets

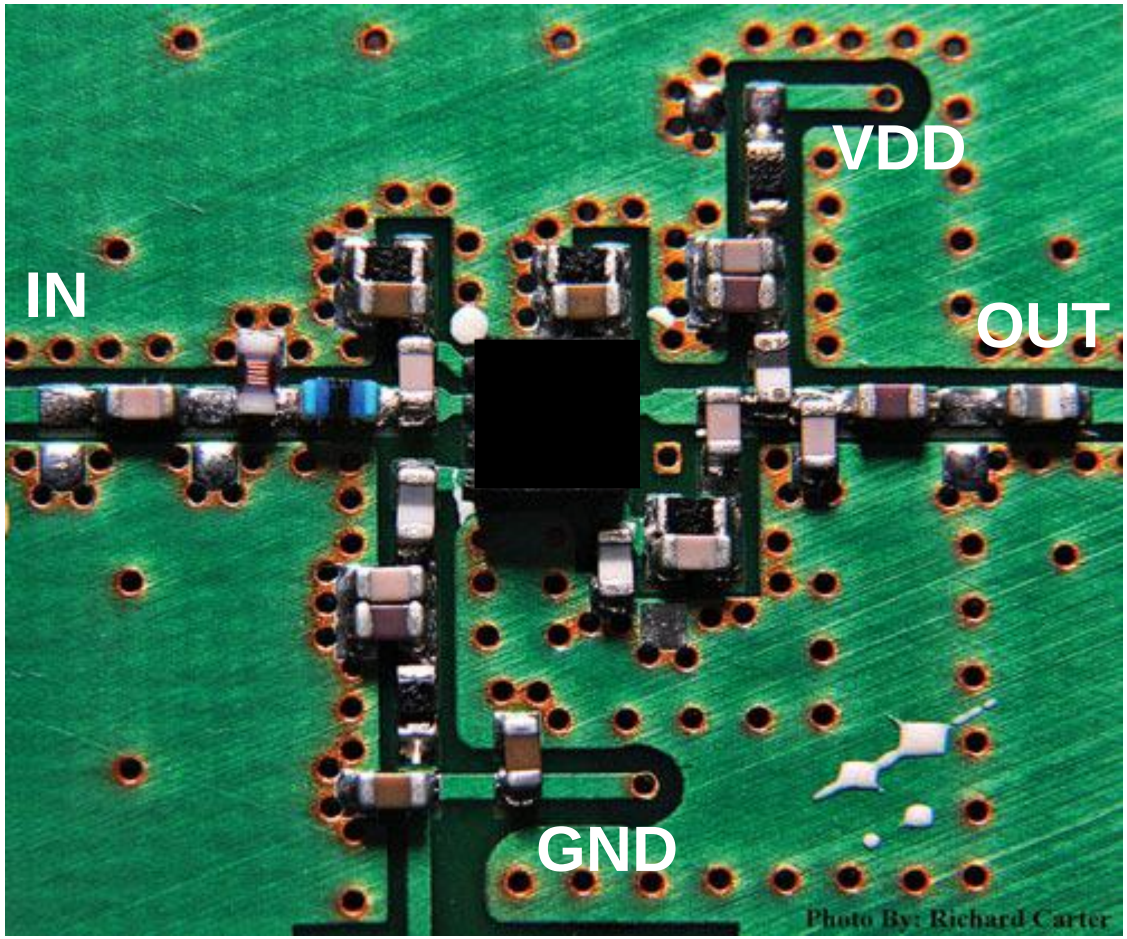
A single cabinet

A single rack

State-of-the-art BS Transceiver



And a single RF IP block: LNA



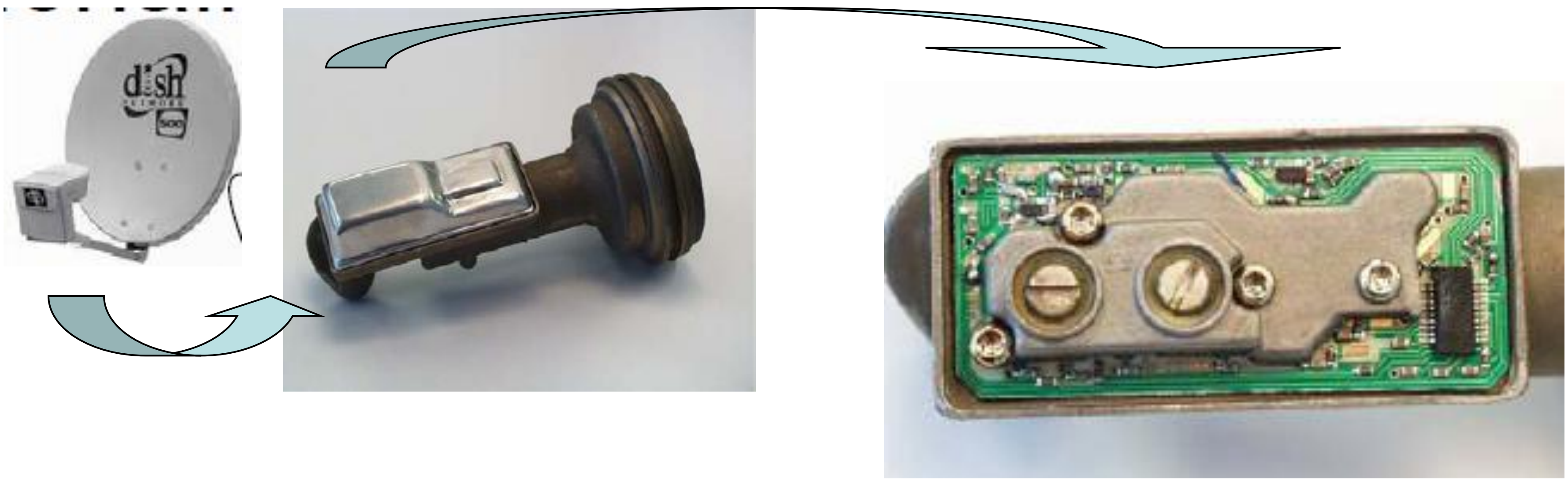
Rx LNA at 900MHz:
22 SMD components around a single pHEMT GaAs device!

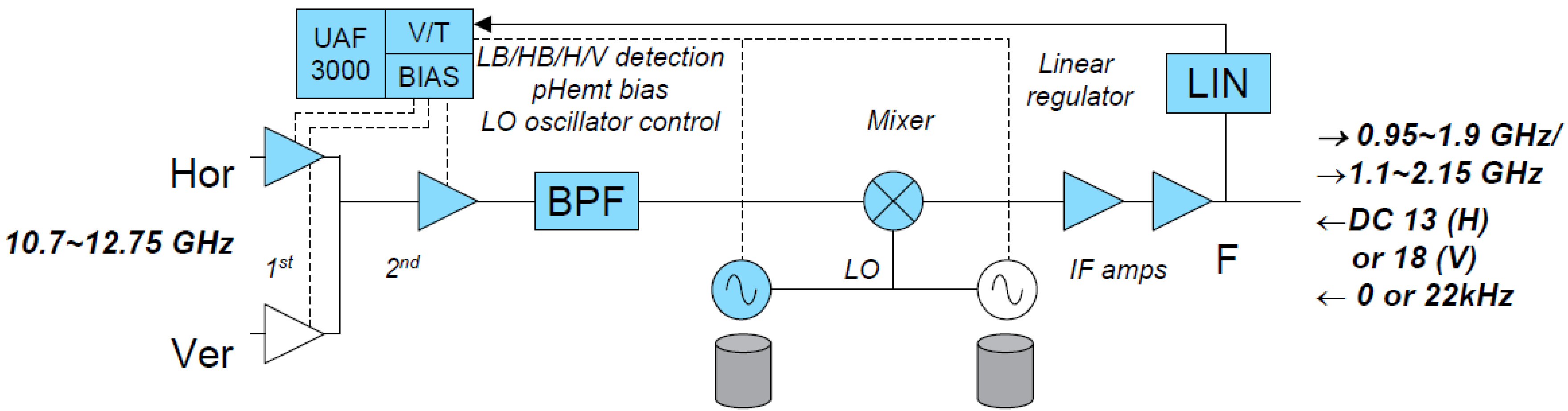
Cellular base station

- **Observation 1: Discrete components**
  - Expensive
  - Compound semiconductor technology
  - …
- **Observation 2: Duplication**
  - Expensive

Why if we can reach impressive integration levels in the handheld?

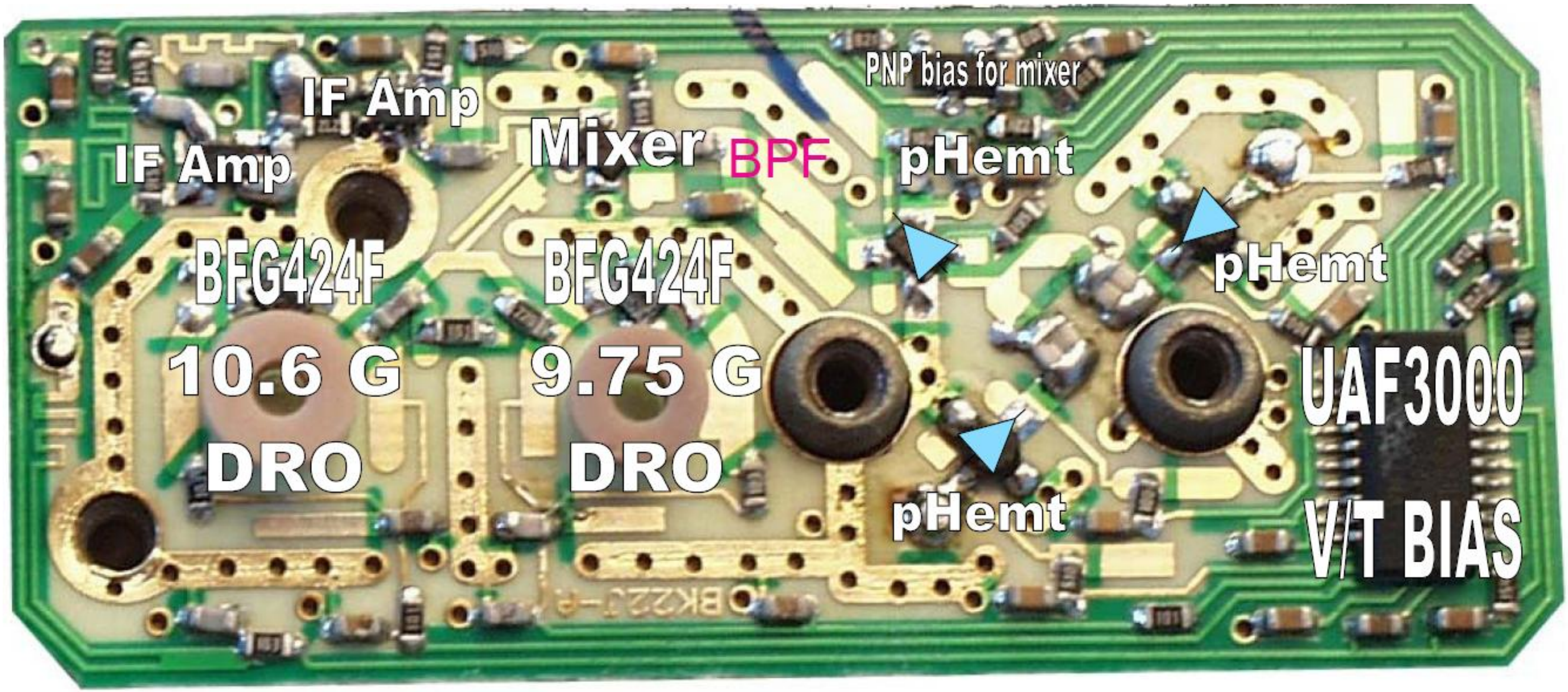
Satellite infrastructure: Ku band





Low Noise Block (LNB) down converter

State-of-the-art Ku LNB



discrete implementation using mainly <u>Compound Semiconductor Technologies</u> (pHMET GaAs)

Satellite infrastructure

- **Observation: Discrete components**
  - Expensive
  - Compound semiconductor technology
  - Manual trimming
  - …

Why is this down converter not integrated?

Wireless infrastructure

it's performance!!

Cost is not an issue
Size is not really an issue
Power dissipation is not an issue

A few examples: base station LNA

900MHz	Spec HH	Spec BS	avago	Asia-Pacific Microwave Conf. 2000	JSSC 2007
NF [dB]	< 2	< 0.6	0.53	1.35	0.2 non-50Ω
1-dB OCP [dBm]	> -5	> +15	+18	+8	+1
OIP3 [dBm]	> 8	> +30	+33	+22	+12
Gain [dB]	> 15	> 15	18	13	17
S11 [dB]	< -10	< -20	< -20	< -10	< -11
Pdiss [mW]	low		216	38	43
technology			0.5μm GaAs	0.25μm BiCMOS	90nm CMOS

A few examples: satellite LNA

Ku band

10-12GHz	Spec	NEC	Ellinger 2004	Aspemyr 2006
NF [dB]	< 0.6	0.35	3	2.1
Gain [dB]	> 10	> 13	14	12.3
Pdiss [mW]		20	2.3	11.2
technology		0.25μm GaAs	0.25μm BiCMOS	90nm CMOS

Ka band

18-22GHz	Spec	NEC	Guo 2005	
NF [dB]	< 1	0.7	5.5	
Gain [dB]	> 10	> 13	10	
Pdiss [mW]		20	24	
technology		0.25μm GaAs	0.13μm CMOS	

A few examples: satellite VCO

15GHz	Hittite	Asia-Pacific Microwave Conf. 2009	BCTM 2007
Frequency	15GHz	13.5GHz	15GHz
PN @ 100kHz [dBm/Hz]	-105	-84.4	-82
Po [dBm]	+7	-4	+2
Pdiss [mW]		4.5	18
technology	GaAs - InGaP	0.18μm CMOS	0.18μm SiGe:C

Content

- **Wireless infrastructures**
  - State-of-the-art
  - **Need for (further) integration**
- (Re) Quest for High Performance RF
  - Technology
  - Design
- Concluding remarks

The need for integration is coming

- **In cellular base stations**
  - Increased density of base stations to cope with data traffic (Shanghai: every 500m!)
  - More standards / bands / phased arrays
  - Power reduction: the ‘green’ label
  - Tower mounted units instead of ‘base’ station
  - Robustness, yield, …

The need for integration is coming

- **In satellite communication**
  - – Next Ka-satellite market India and South Americas: but then price of LNB must reduce
  - – LNB/BUC is powered by Set Top Box (STB)
    - Ultimate goal is the universal QUAD LNB/BUC supplying 4 STBs minimum, but powered by still 1 STB worse case (backward compatible)
      - – Ku-band & Ka-band & both polarizations

The need for integration is coming

- **Wireless infrastructure will benefit from integration**
  - More functionality
  - Improved yield and thus lower cost
  - Improved reliability (ESD, automatic calibration, BIST, adaptive matching, …)
  - less PCB issues at costumer site
  - Paves the path towards spatial selectivity to mitigate interference, support tracking, boost TX power, etc.

- **But this all requires Si-based RF solutions**
  - GaAs-like technology lack dense integration

Wireless infrastructure

so we need Si solutions

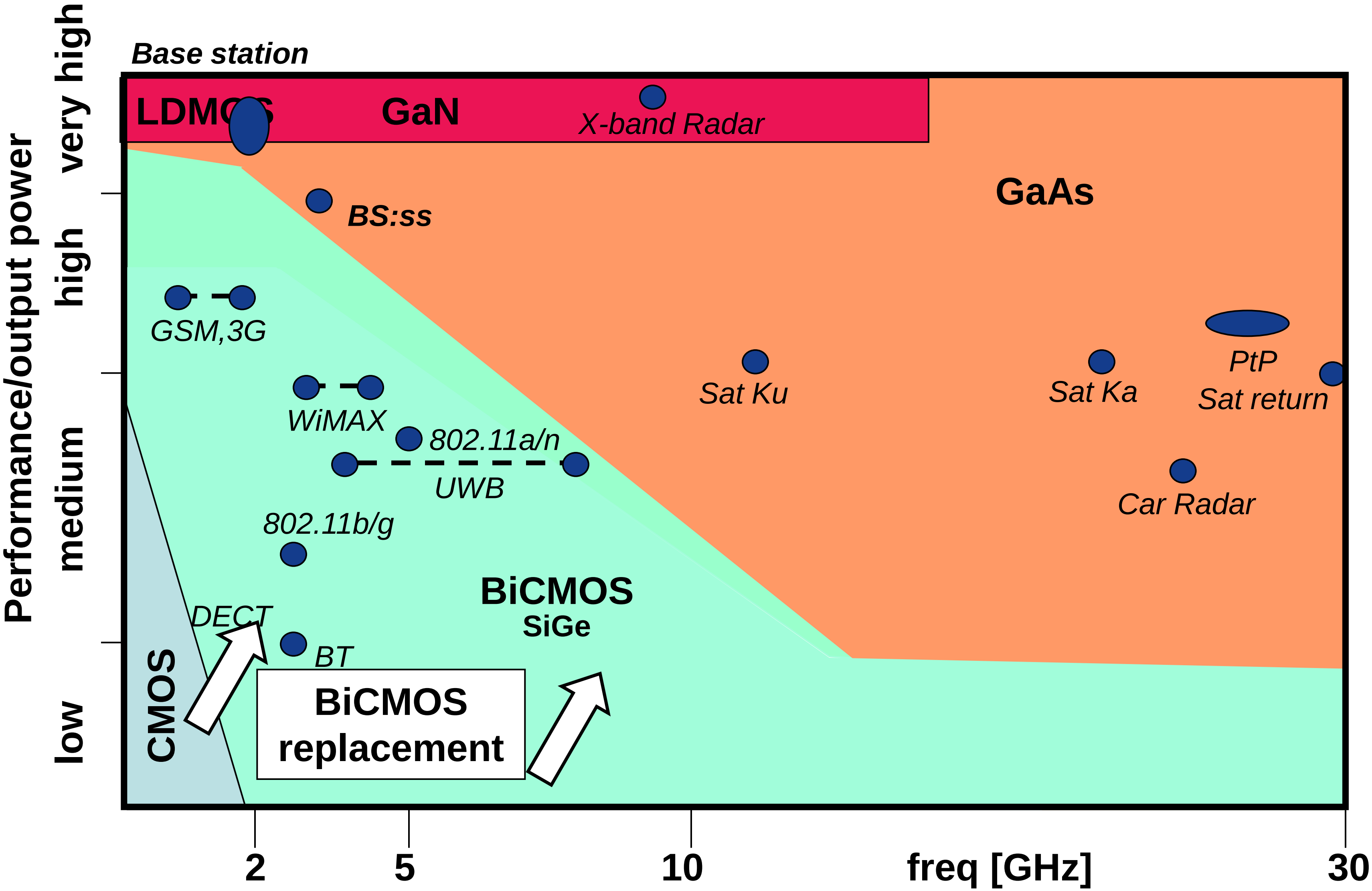
Two-step approach:

Improve Si-technology
Different architecture/circuit design

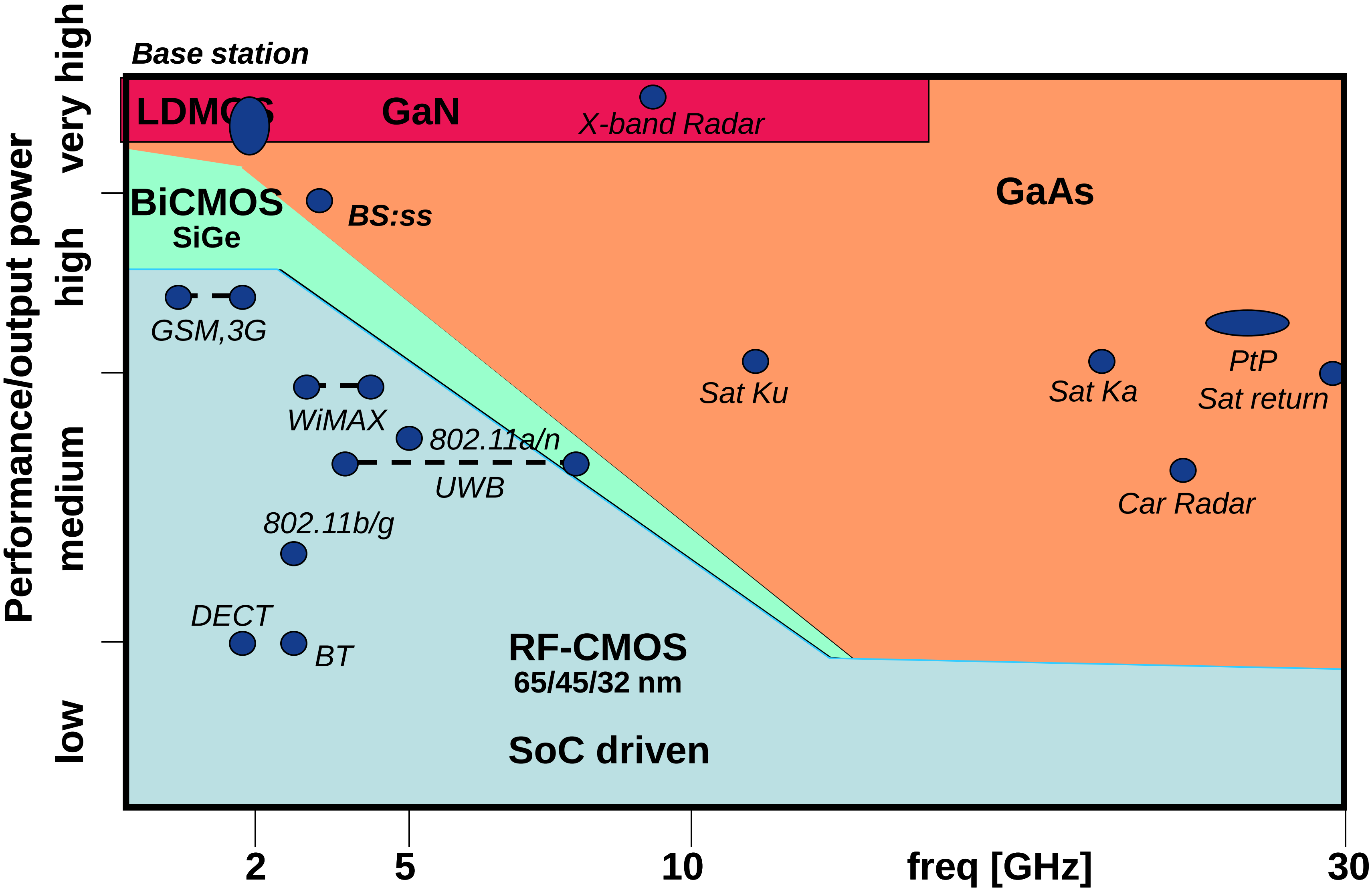
Content

- Wireless infrastructures
  - State-of-the-art
  - Need for (further) integration
- (Re) Quest for High Performance RF
  - Technology
  - Design
- Concluding remarks

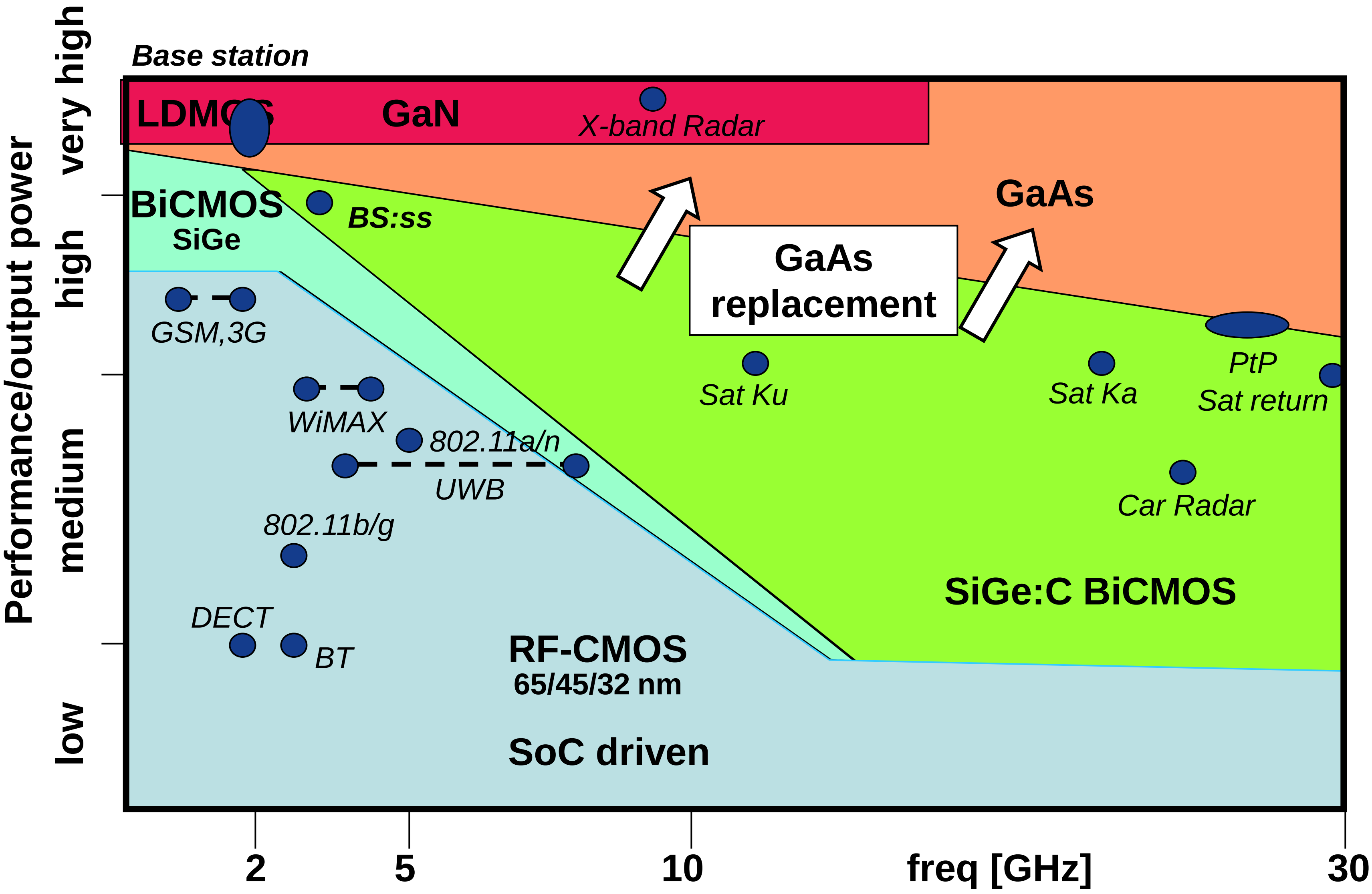
Improve Si-technology



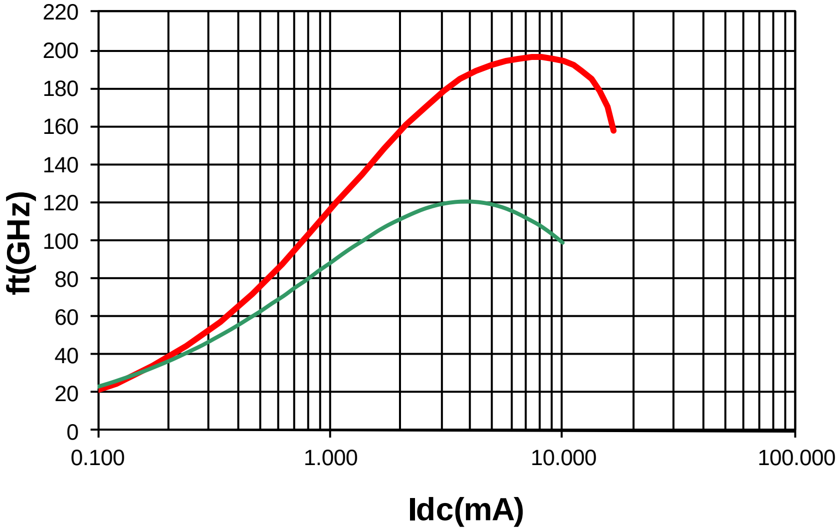
Improve Si-technology

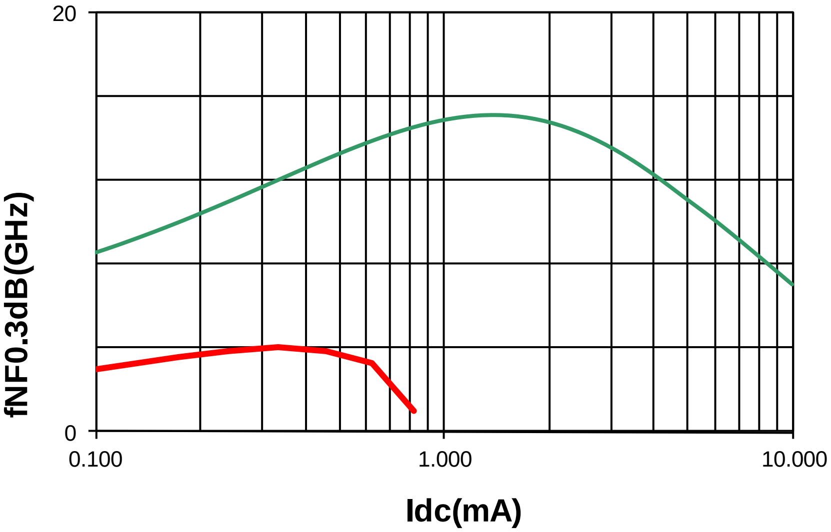


Improve Si-technology



Technology: SiGe:C front-end





SiGe:C NXP technology
TSMC 65nm CMOS

65nm NMOS → capacitive nature
SiGe:C → real part (base resistance)

Impedance match

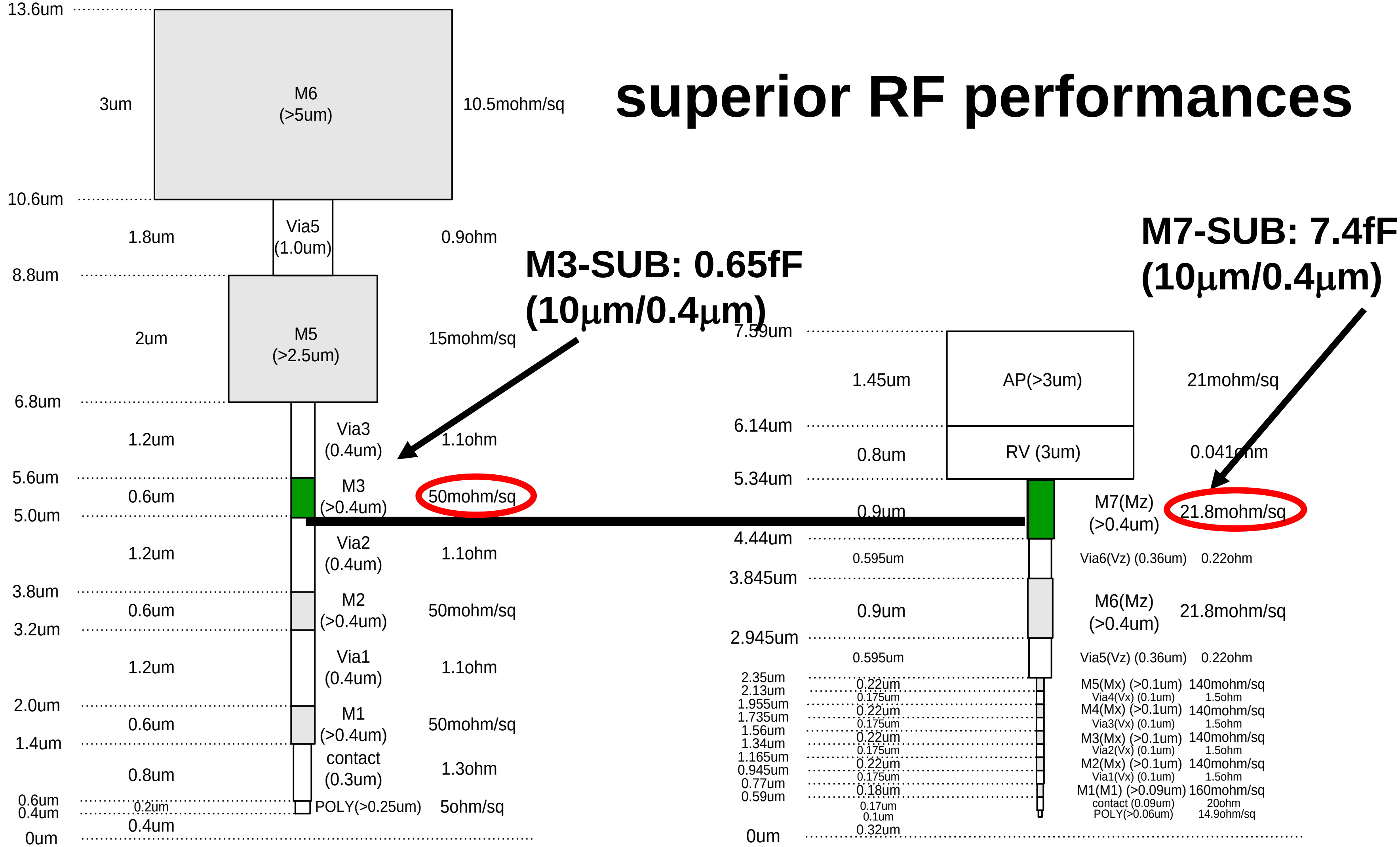
$$Z_s = Z_i^* \Rightarrow P_{s,av} = P_{i,del}$$

Noise match

$$Z_s = Z_{opt}$$

Technology SiGe:C: back-end

superior RF performances



SiGe:C NXP technology **65nm CMOS TSMC**

Content

- Wireless infrastructures
  - State-of-the-art
  - Need for (further) integration
- (Re) Quest for High Performance RF
  - Technology
  - Design
- Concluding remarks

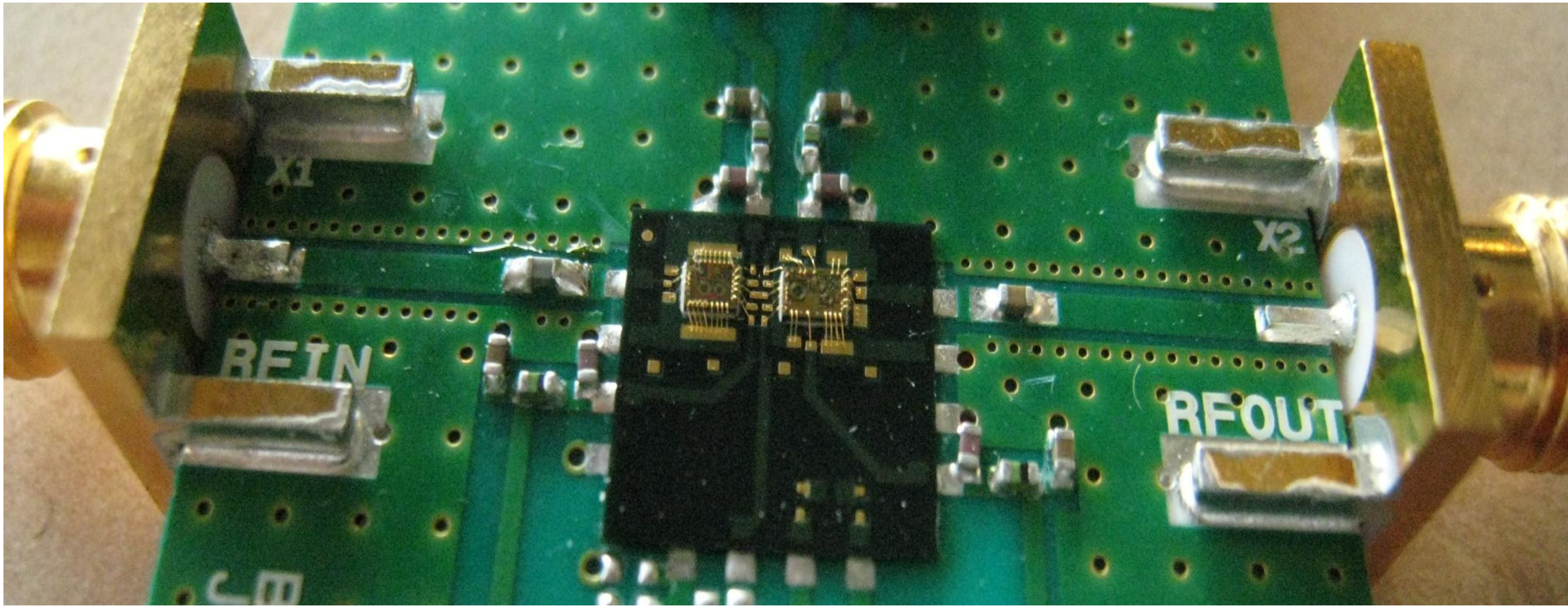
High performance RF design

Use the density of Si-based technology

- Use advanced architectures
- Use digital!
  - Adaptivity
  - Calibration
  - Signal processing power
  - …

and a mix of disciplinary fundamental research (IC design, EM, SP, …)

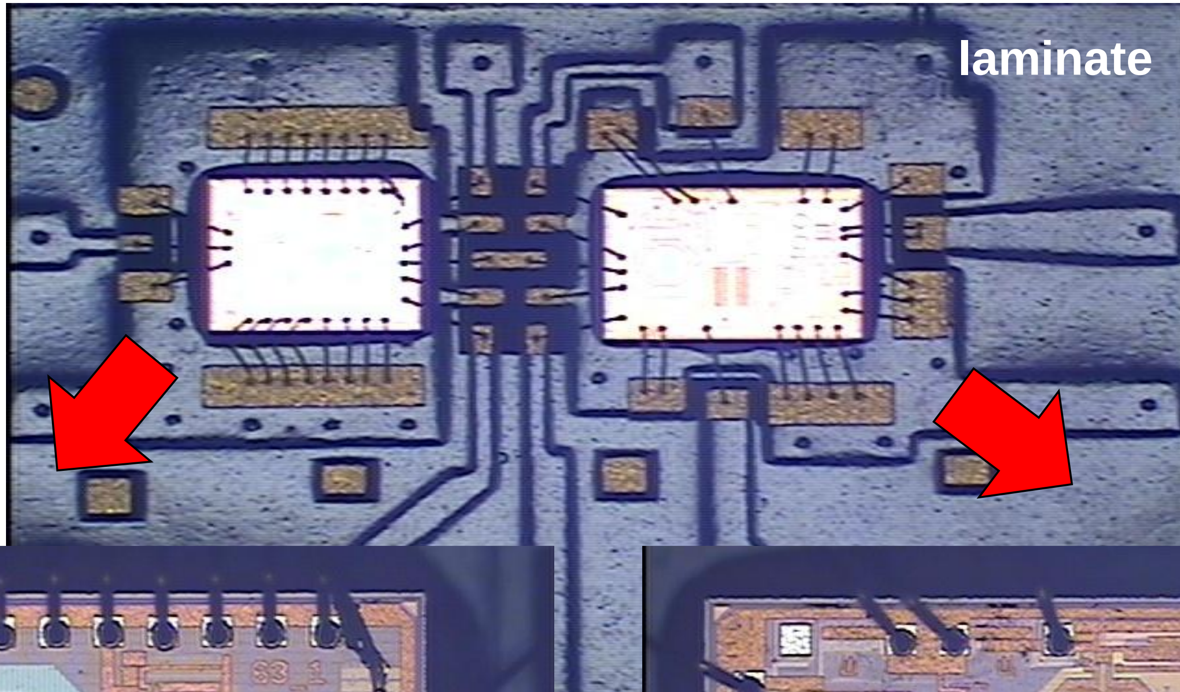
An example: BST LNA

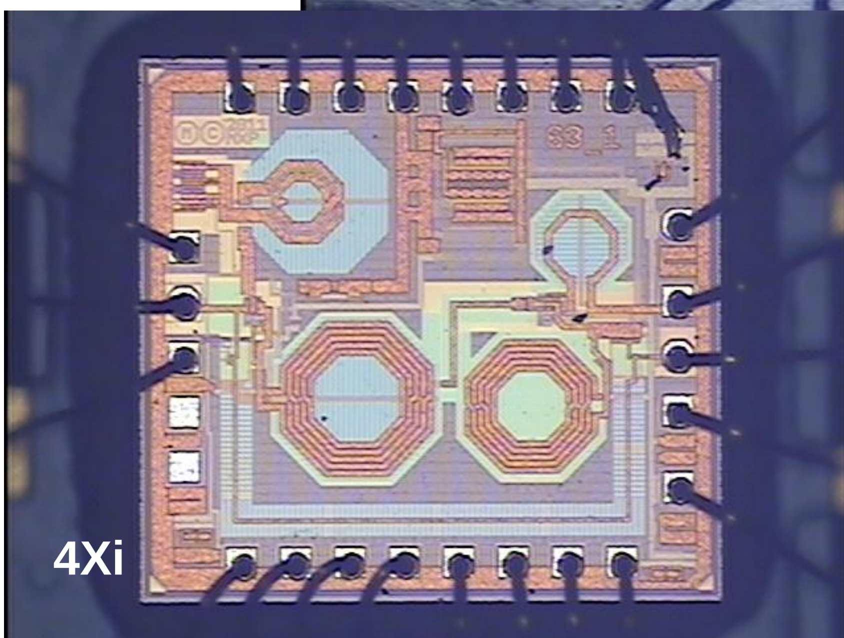


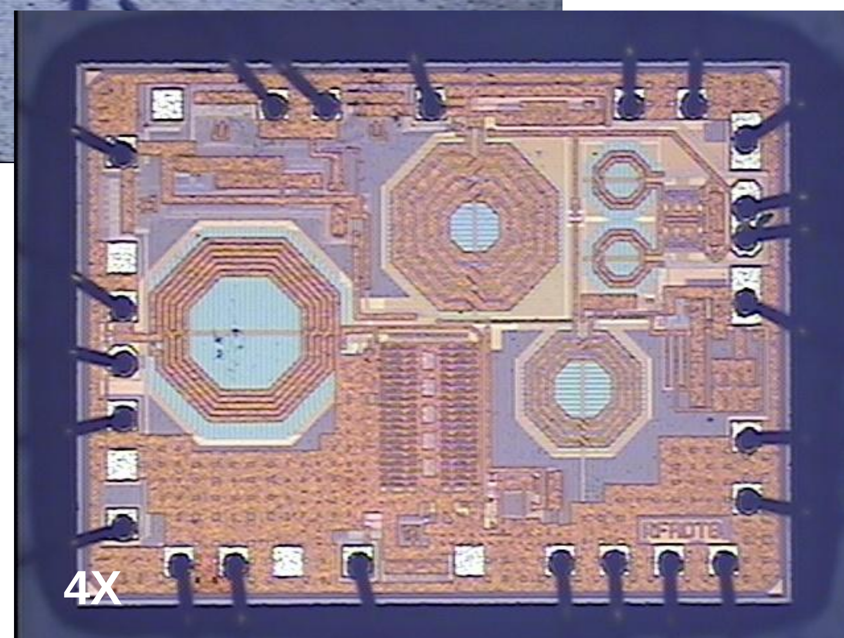
Package: HLQFN16R

31

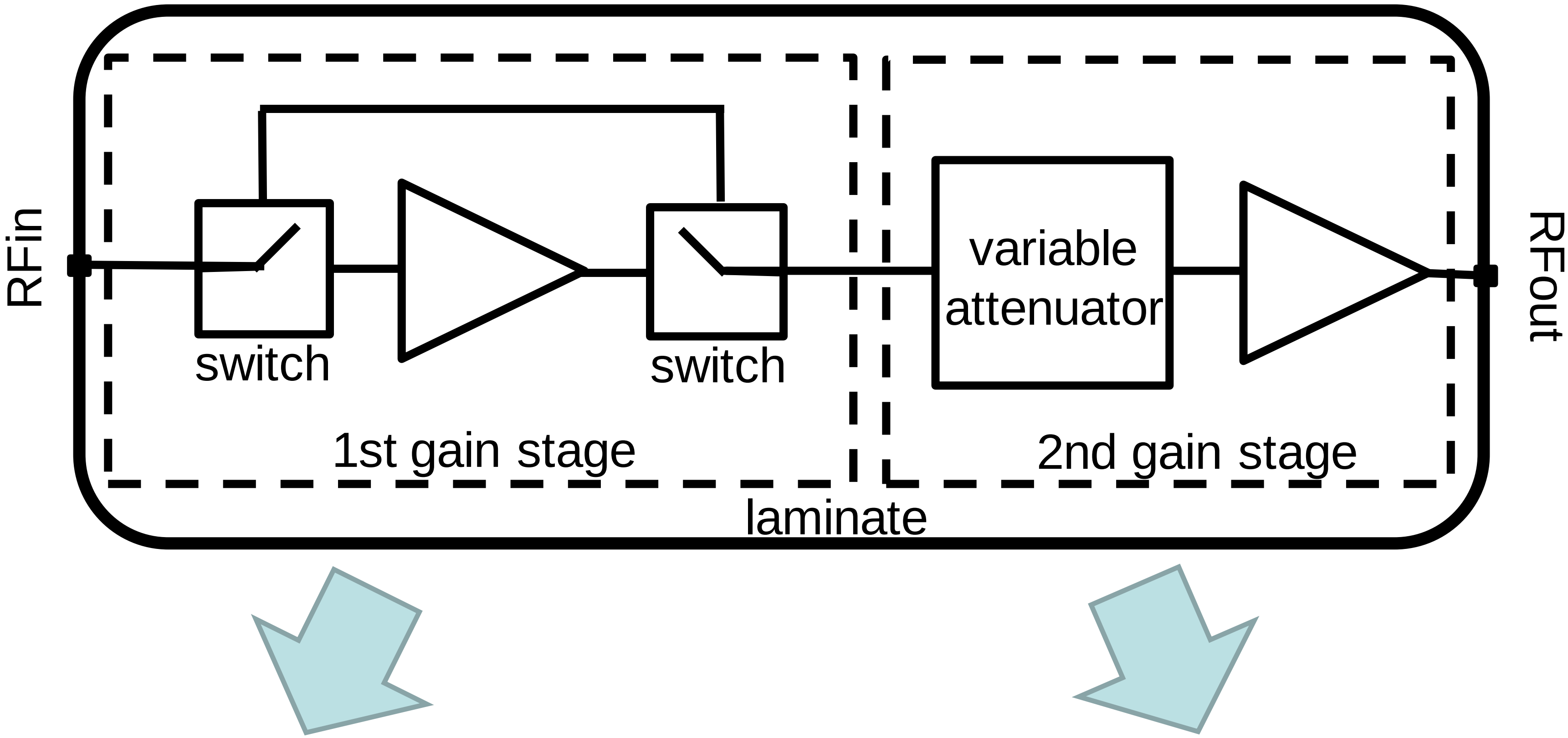
Die photo's







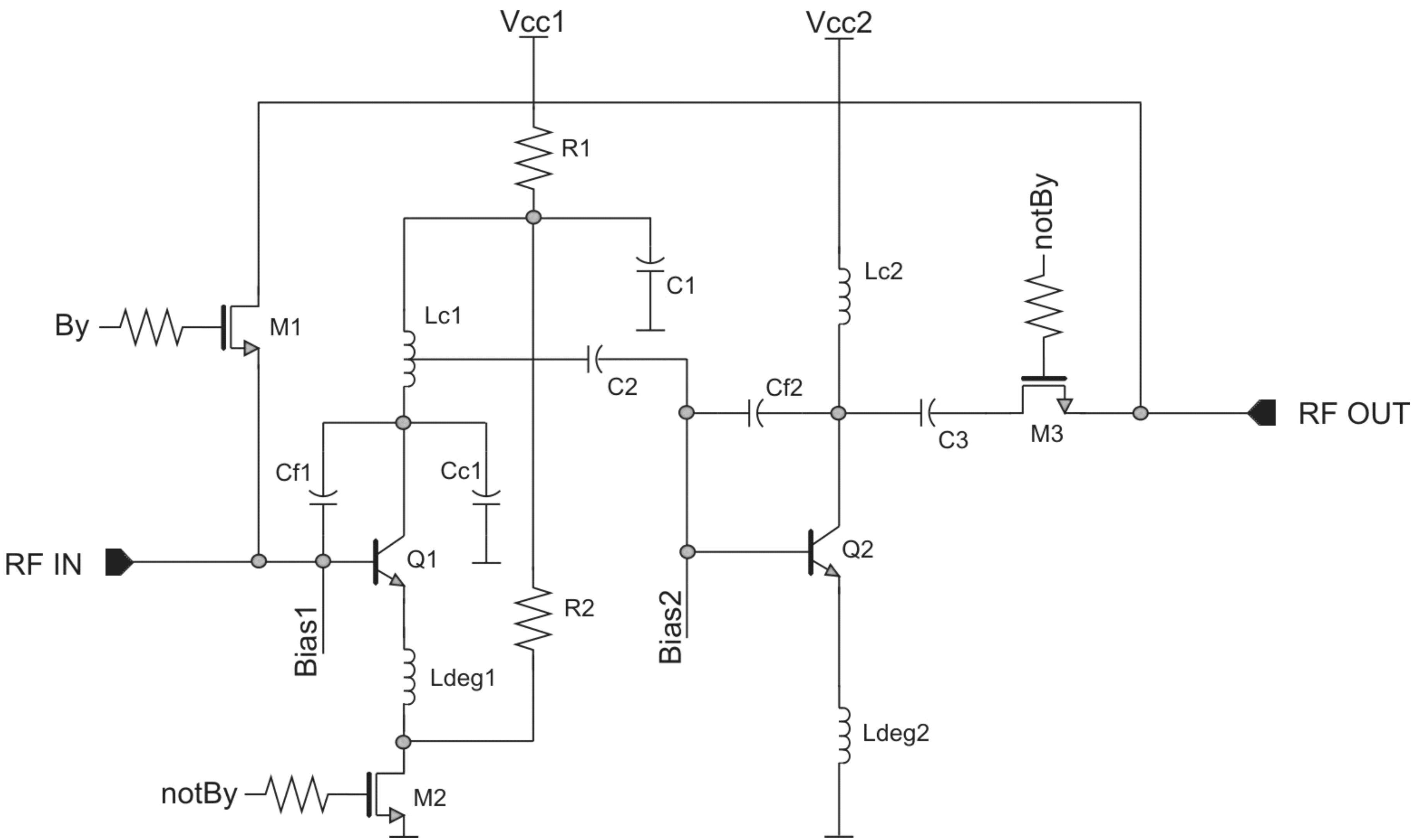
Why a Module?



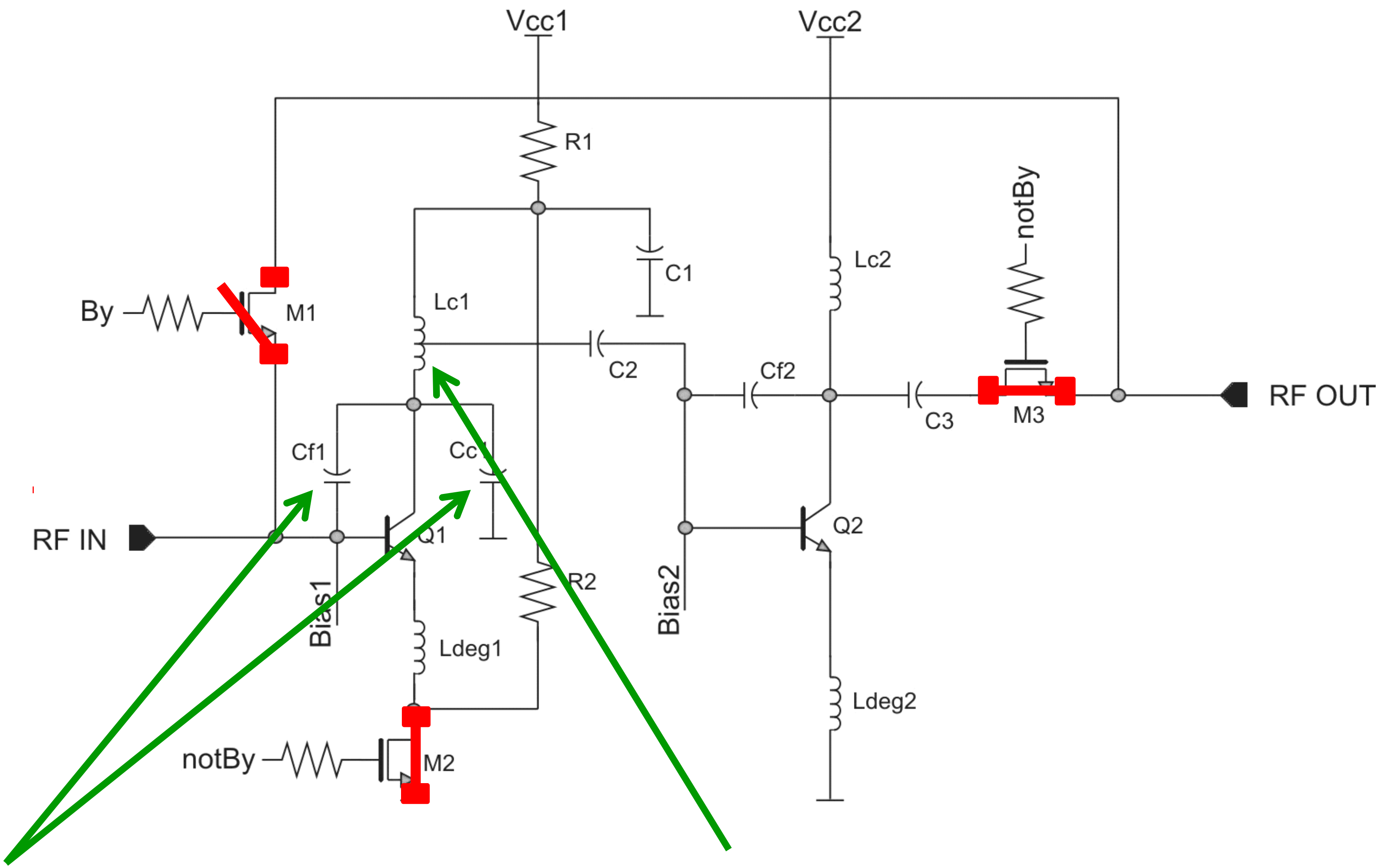
0.25µm SiGe:C BiCMOS
ft = 216GHz, BVceo = 1.45V
NFmin (@2GHz) ≈ 0.4dB

0.25µm SiGe:C BiCMOS
ft = 130GHz, BVceo = 3V
NFmin (@2GHz) ≈ 0.7dB

Design: 1st gain stage



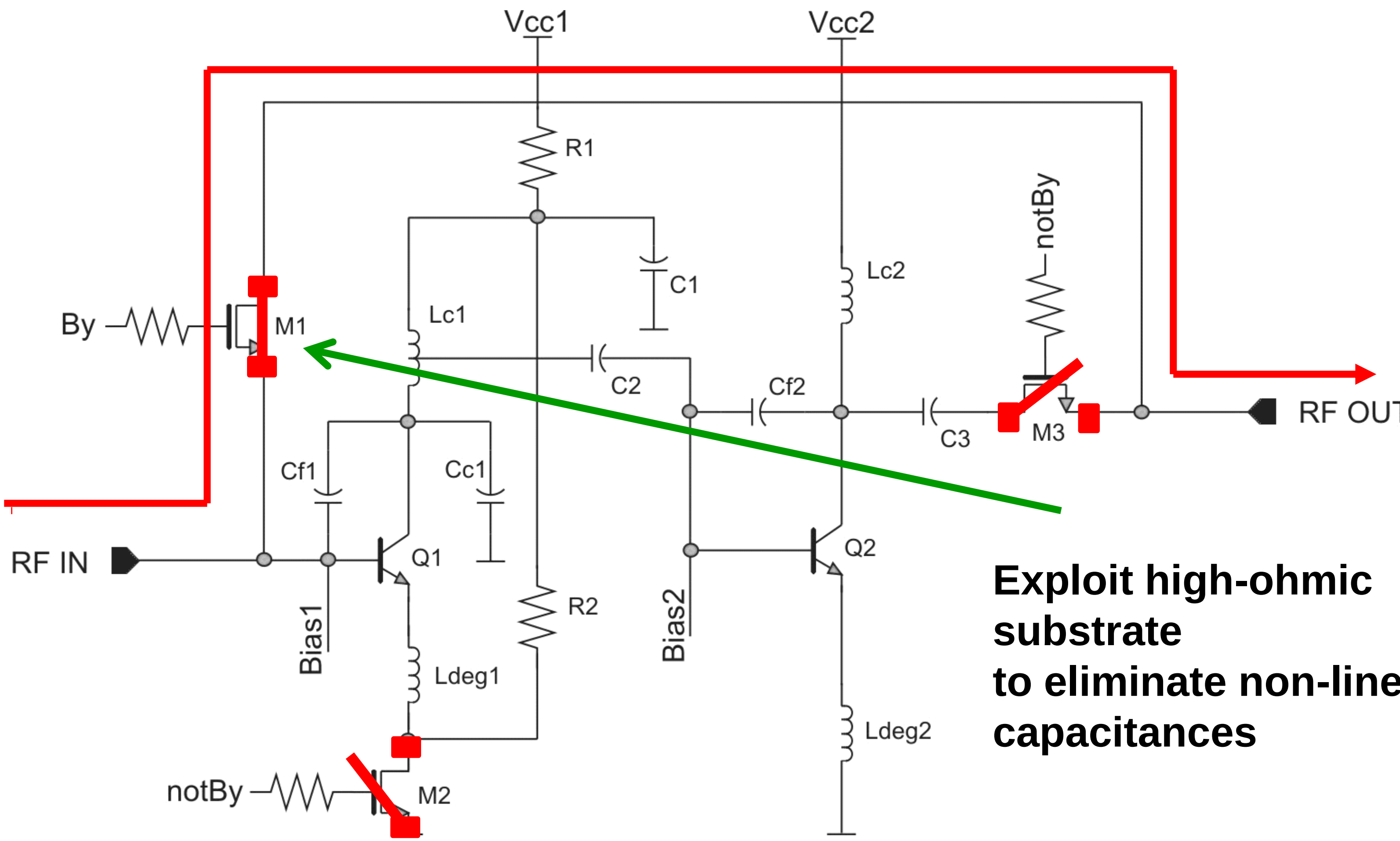
1st gain stage: gain mode



input matching

interstage matching: low impedance

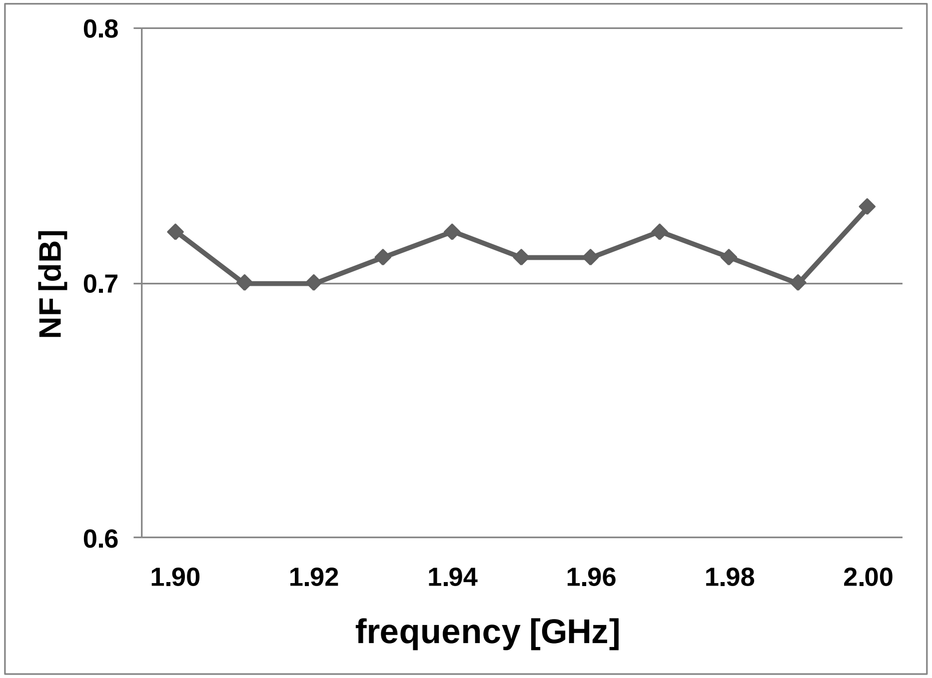
1^{st} gain stage: bypass mode

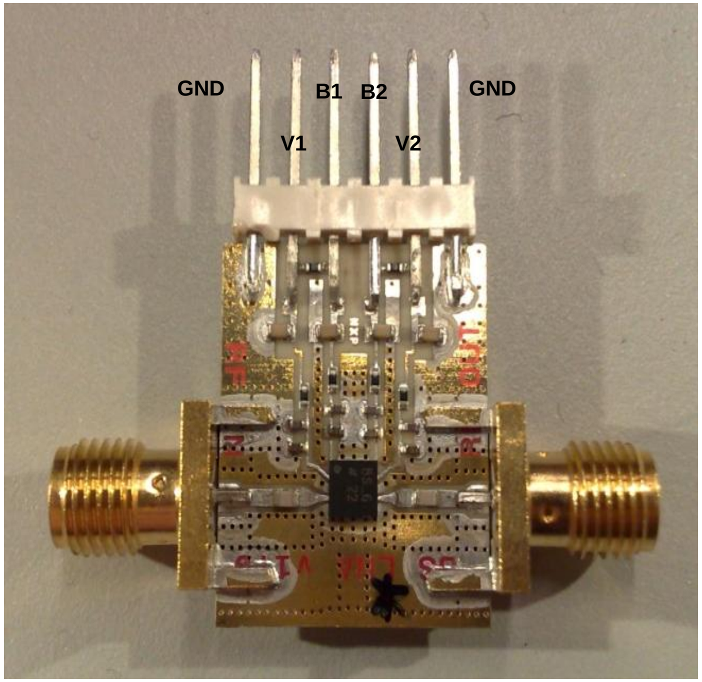


Exploit high-ohmic substrate to eliminate non-linear capacitances

Note: 2nd die will influence the input matching!!

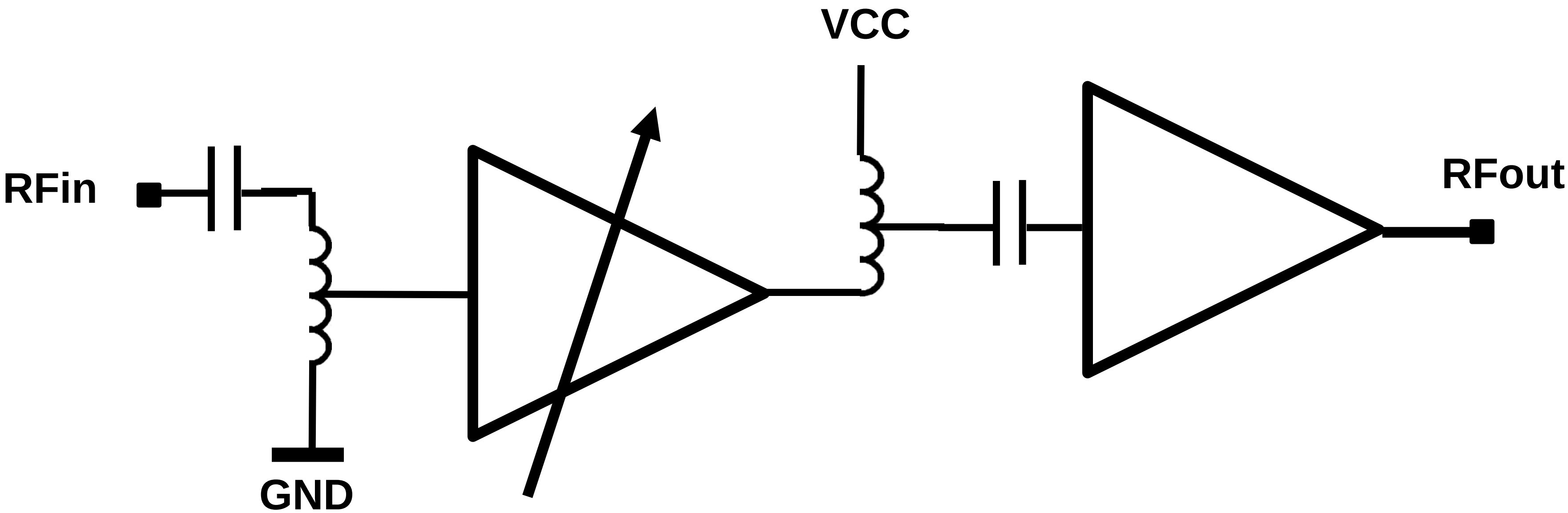
Measurement 1st gain stage





Performance	Active mode	Bypass mode
Pdiss [mW]	350	0
Gain [dB]	19	-1.1
Input IP3 [dBm]	+14	+41
Output IP3 [dBm]	+33	+40
Output CP1dB [dBm]	+15	> +15

Design: 2nd gain stage

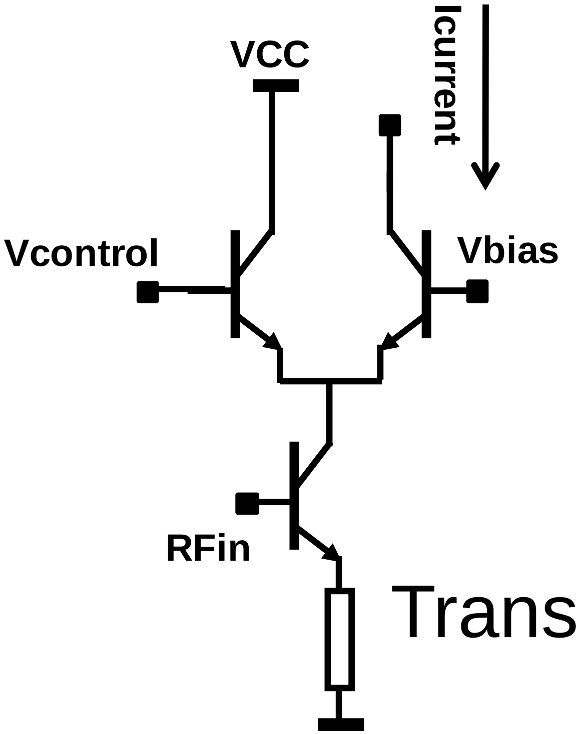


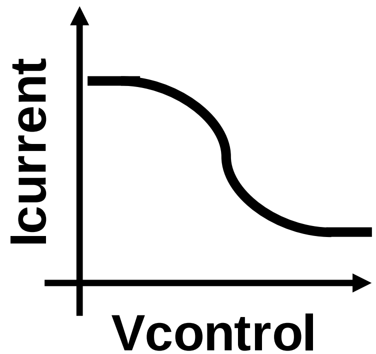
input matching **variable attenuator** **output stage**

0 – 30 dB

High OIP3

Design: variable attenuator

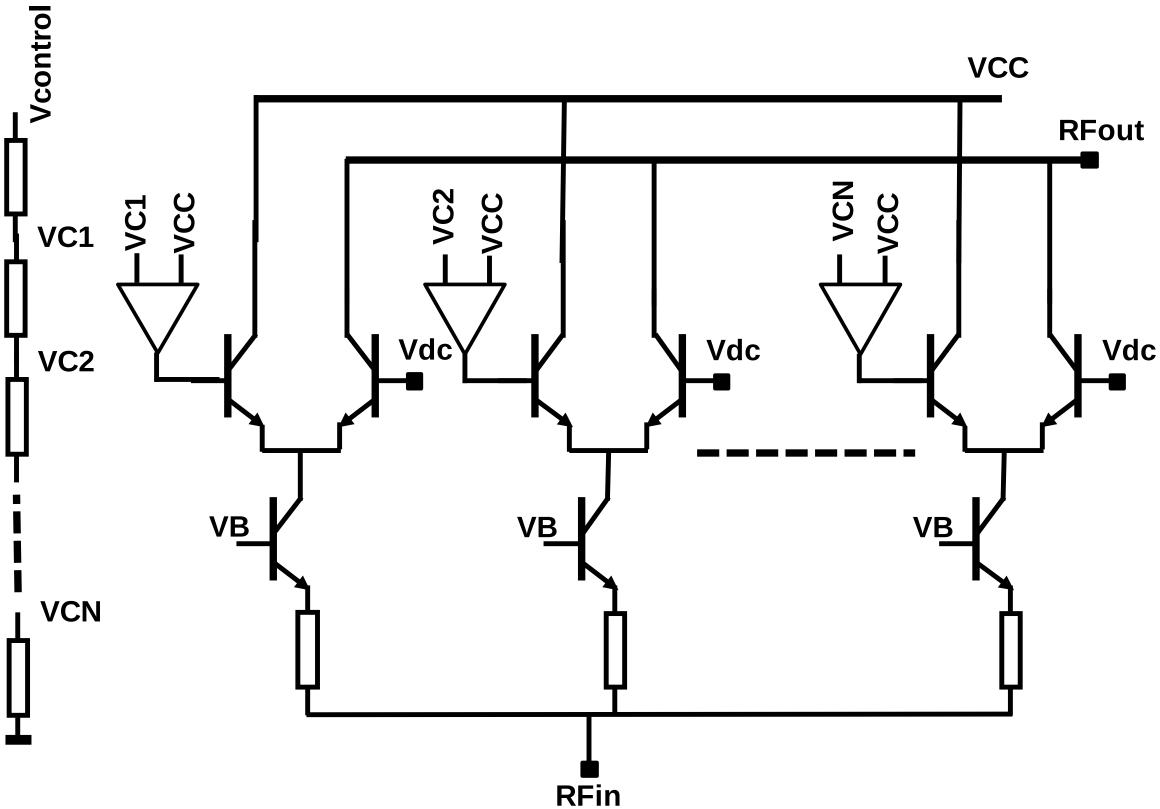


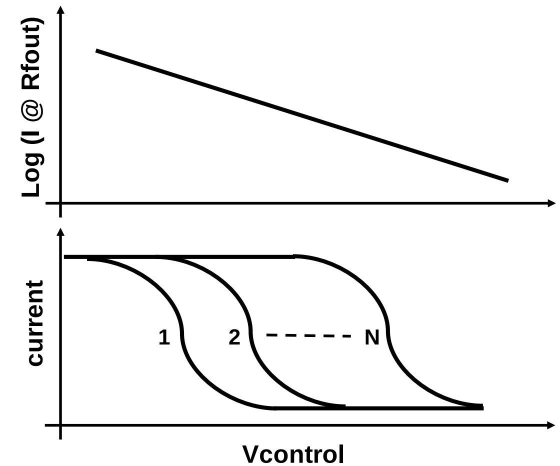


Translinear section instead of MOS switches

- better linearity
- very good reverse isolation
- slightly higher NF
- gain

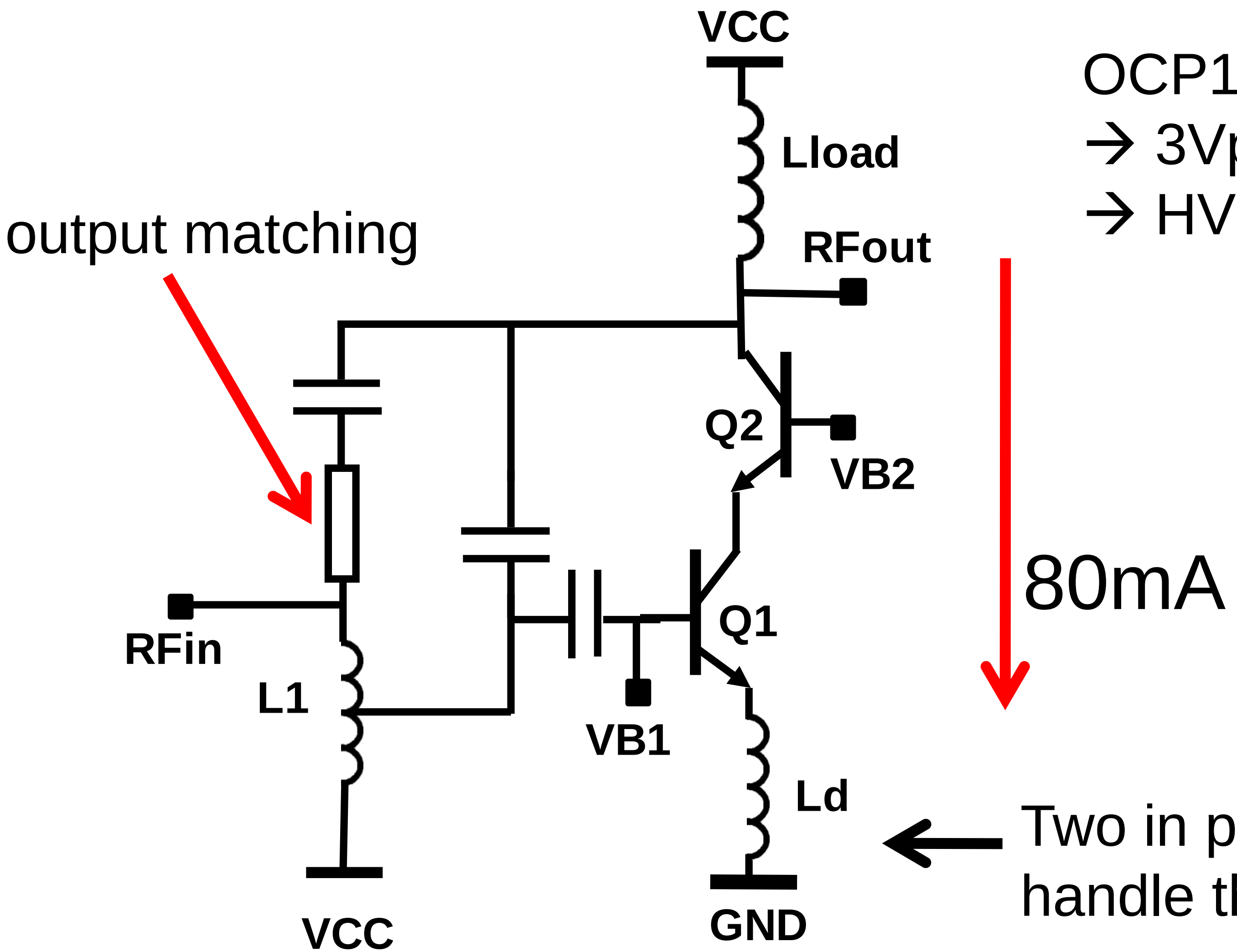
Design: variable attenuator





	JSSC 2008	JSSC 2011	This work
NF	3.5	1.5	6
IIP3	22	17	32

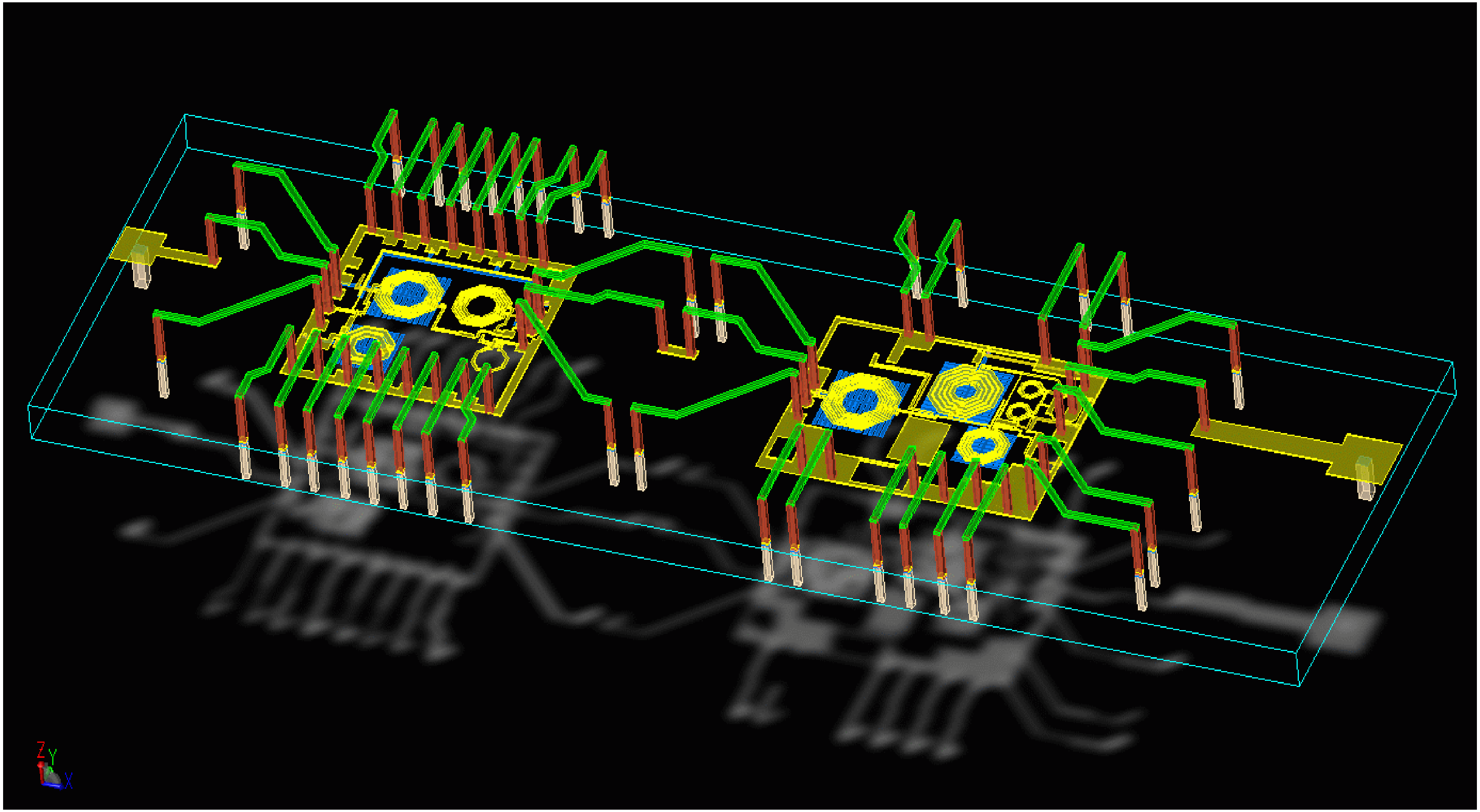
Design: output stage



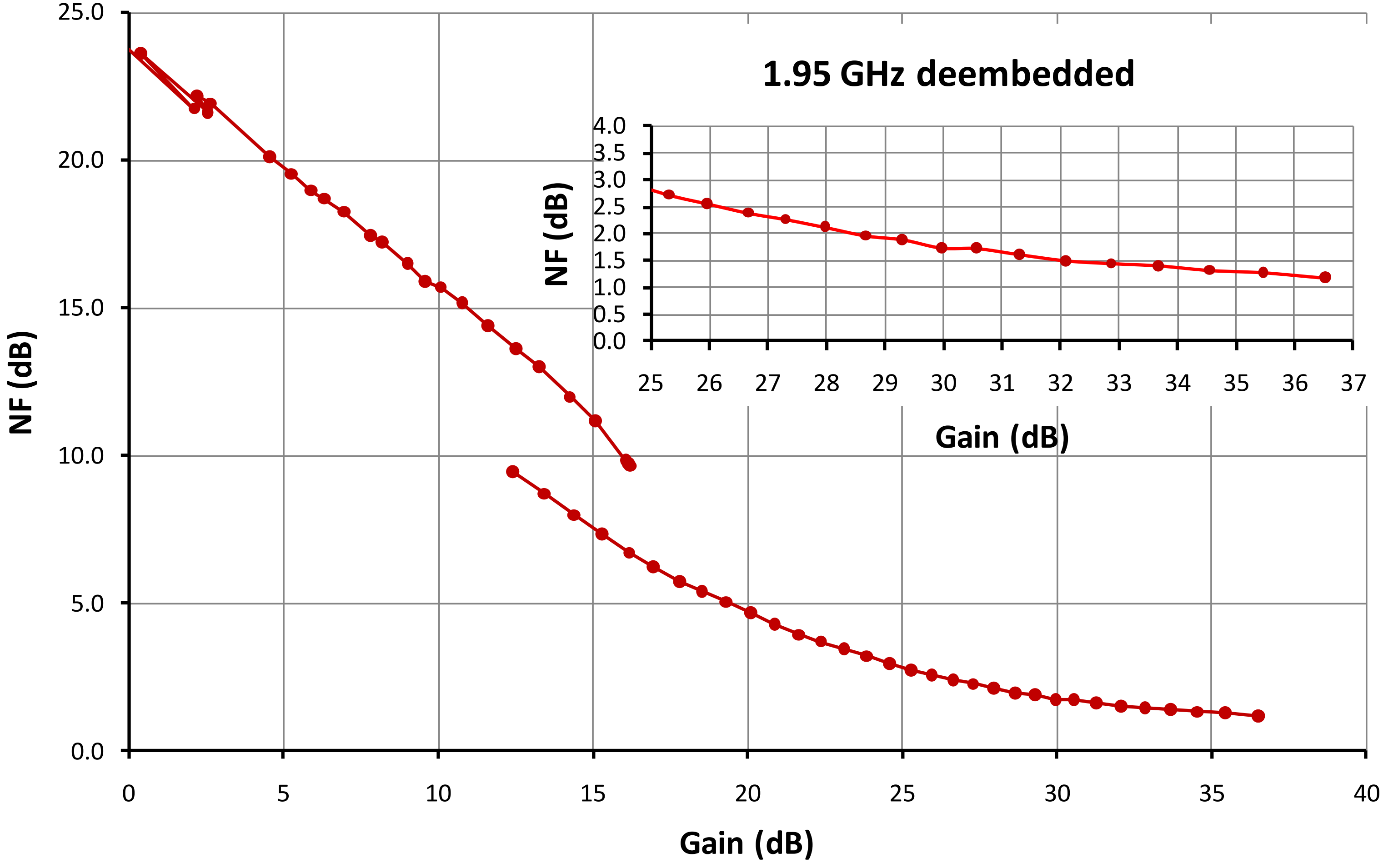
OCP1dB = +20dBm
→ 3Vpeak @ 50Ω
→ HV devices

Two in parallel to handle the current

Design: 2 dies

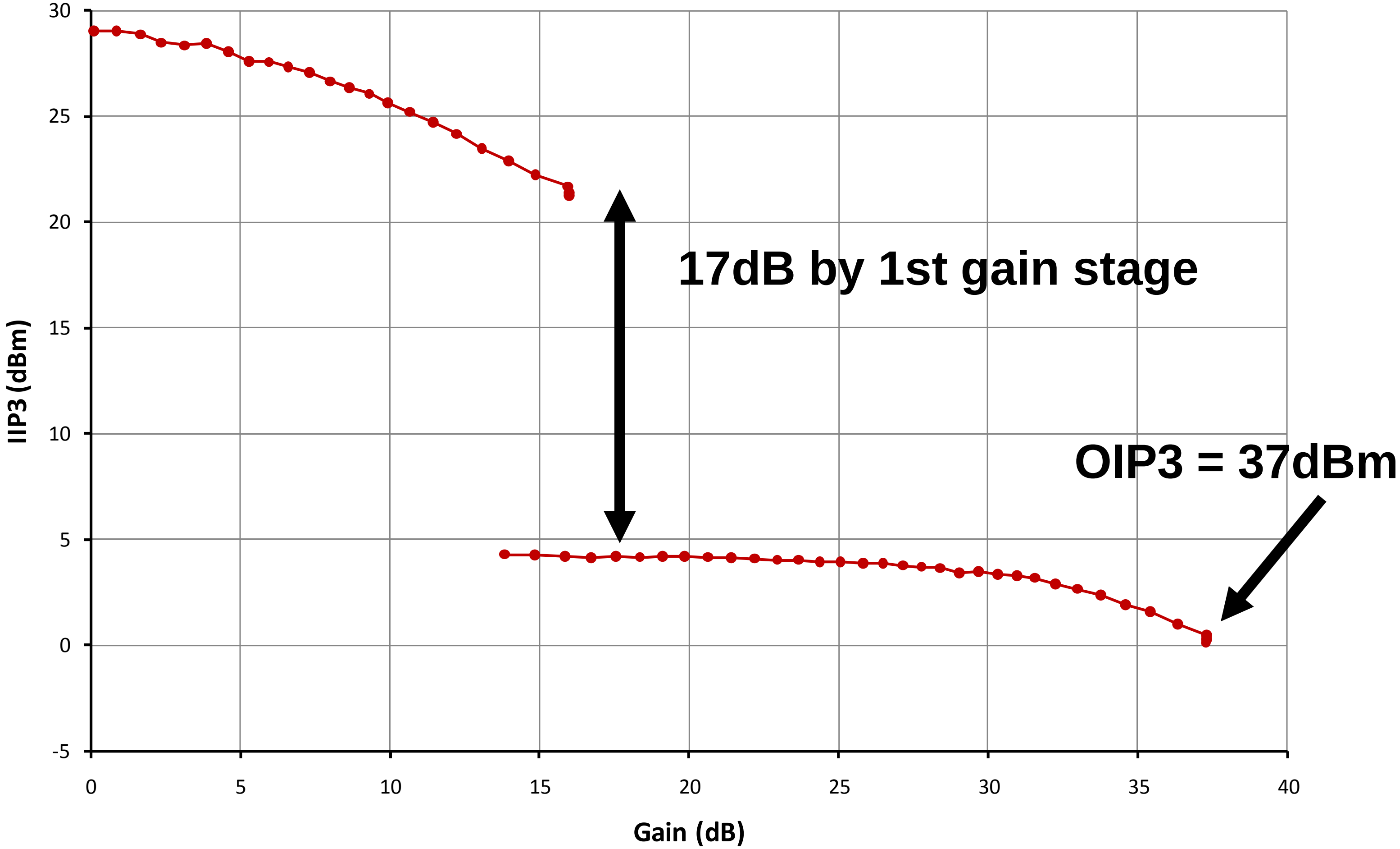


Measurements: NF vs. Gain



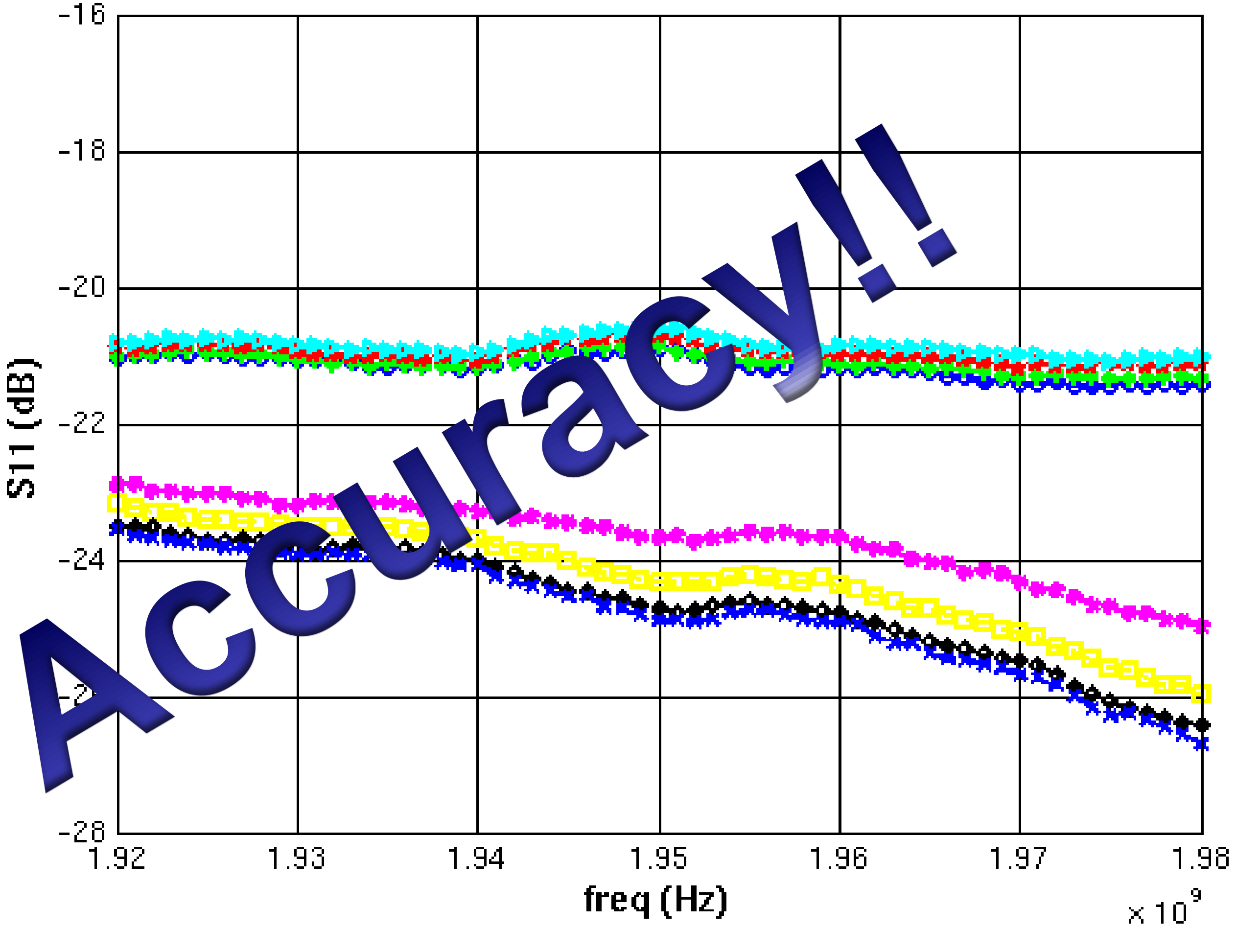
Measurements performed at 65°C

Measurements: IIP3 vs. Gain

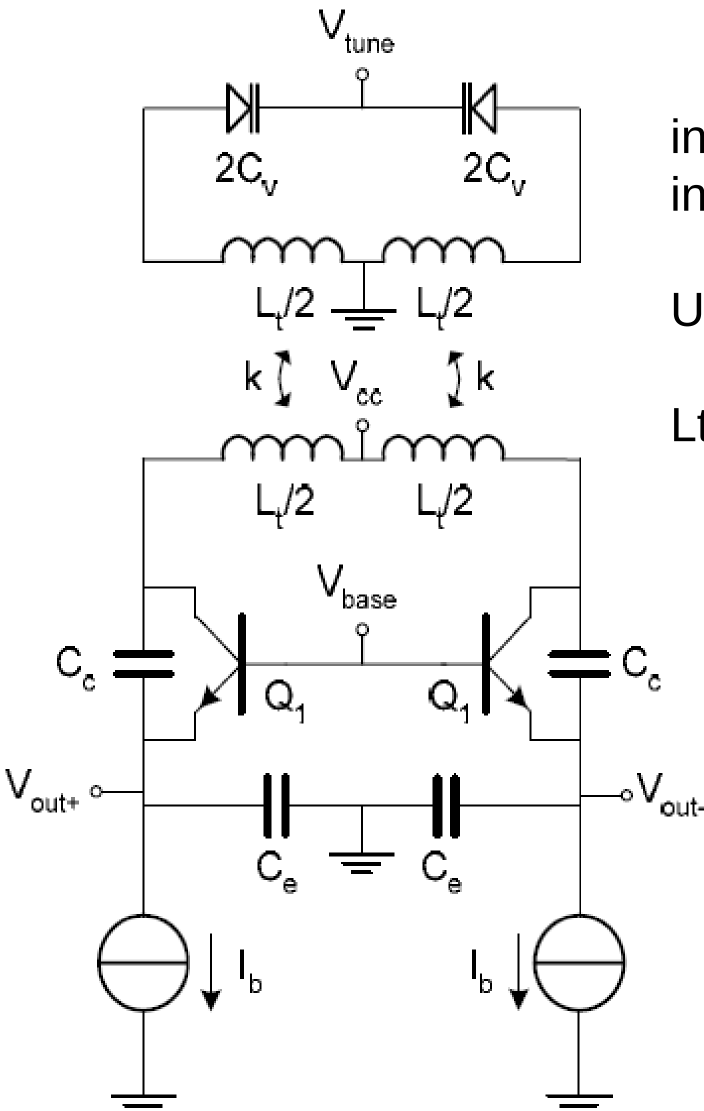


Measurements performed at 65^{o}C

Measurements: S11 vs. Gain



Some examples: Ka VCO



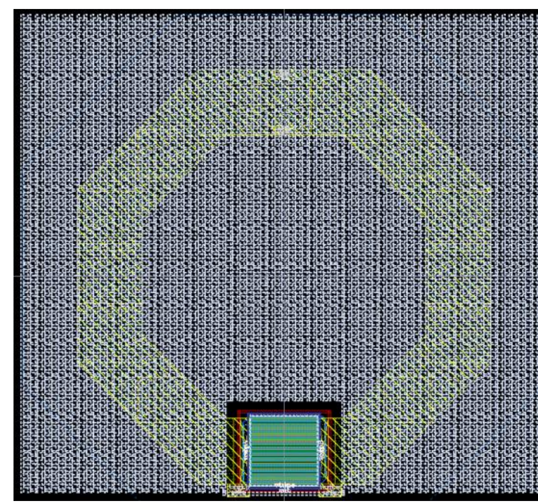
Transformer-based Colpitts VCO

increase L → increase in Q → improves PN
increase L → increase tank impedance → degrades PN

Use transformer:

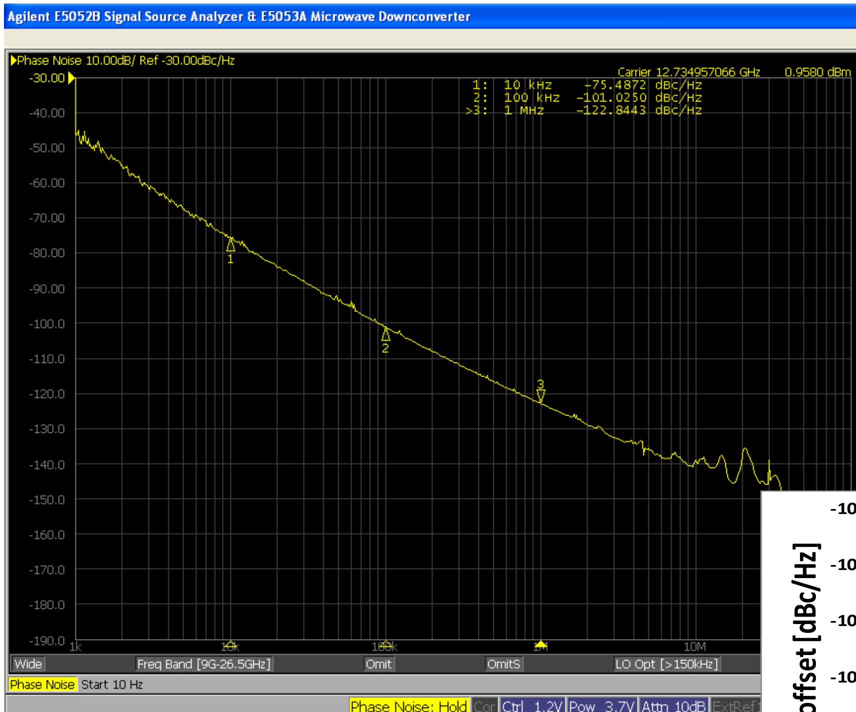
Ltransformer > Ltank

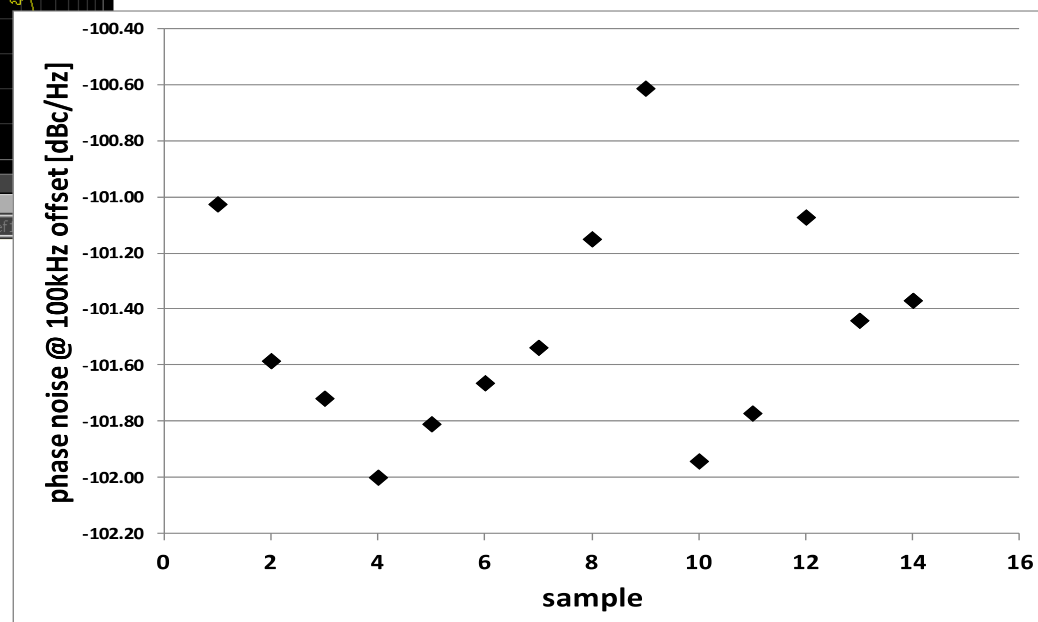
Primary: M6
Secondary: M5+M3



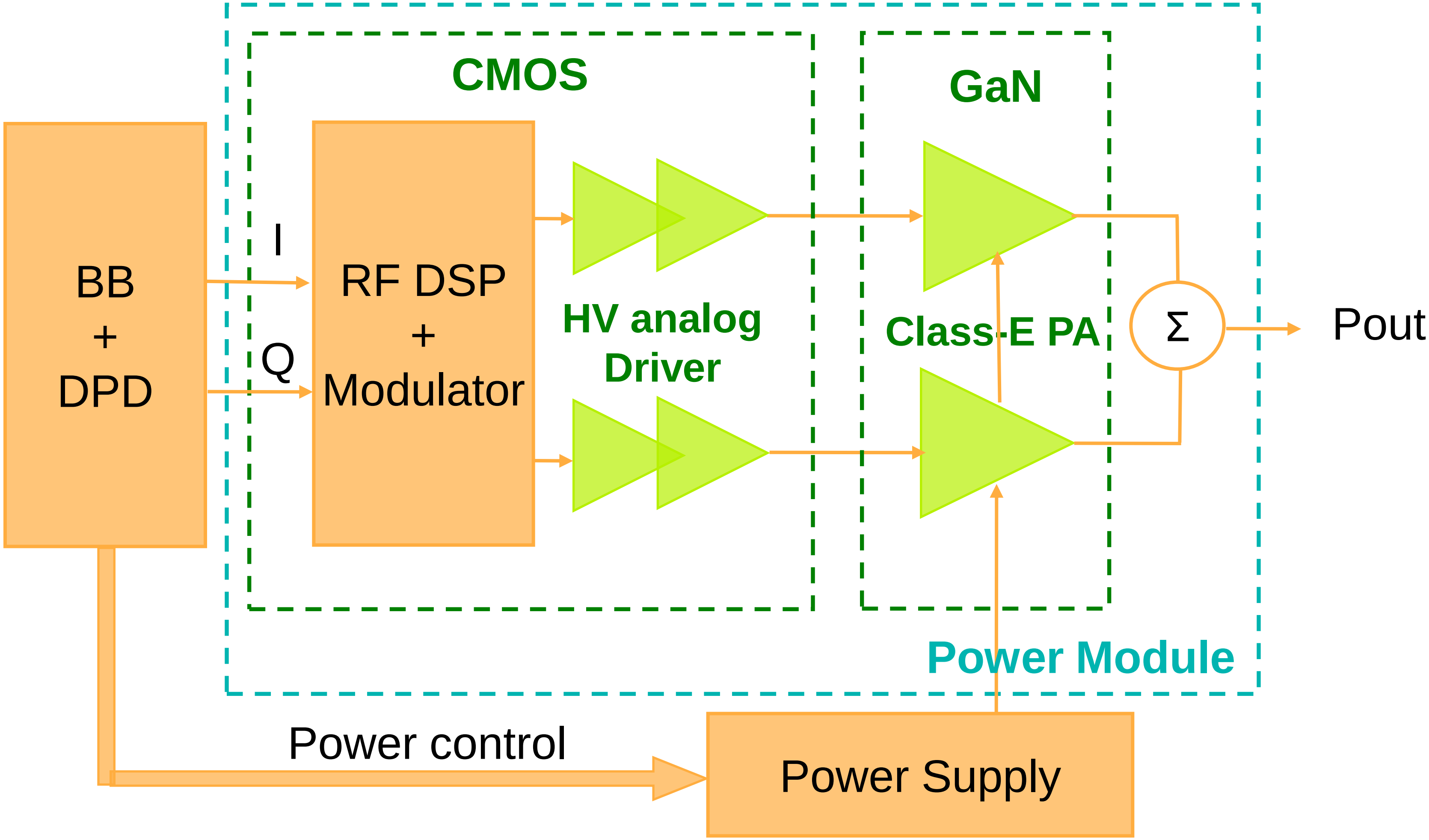
Q=35 @ 17GHz for L=400pH

Some examples: Ka VCO



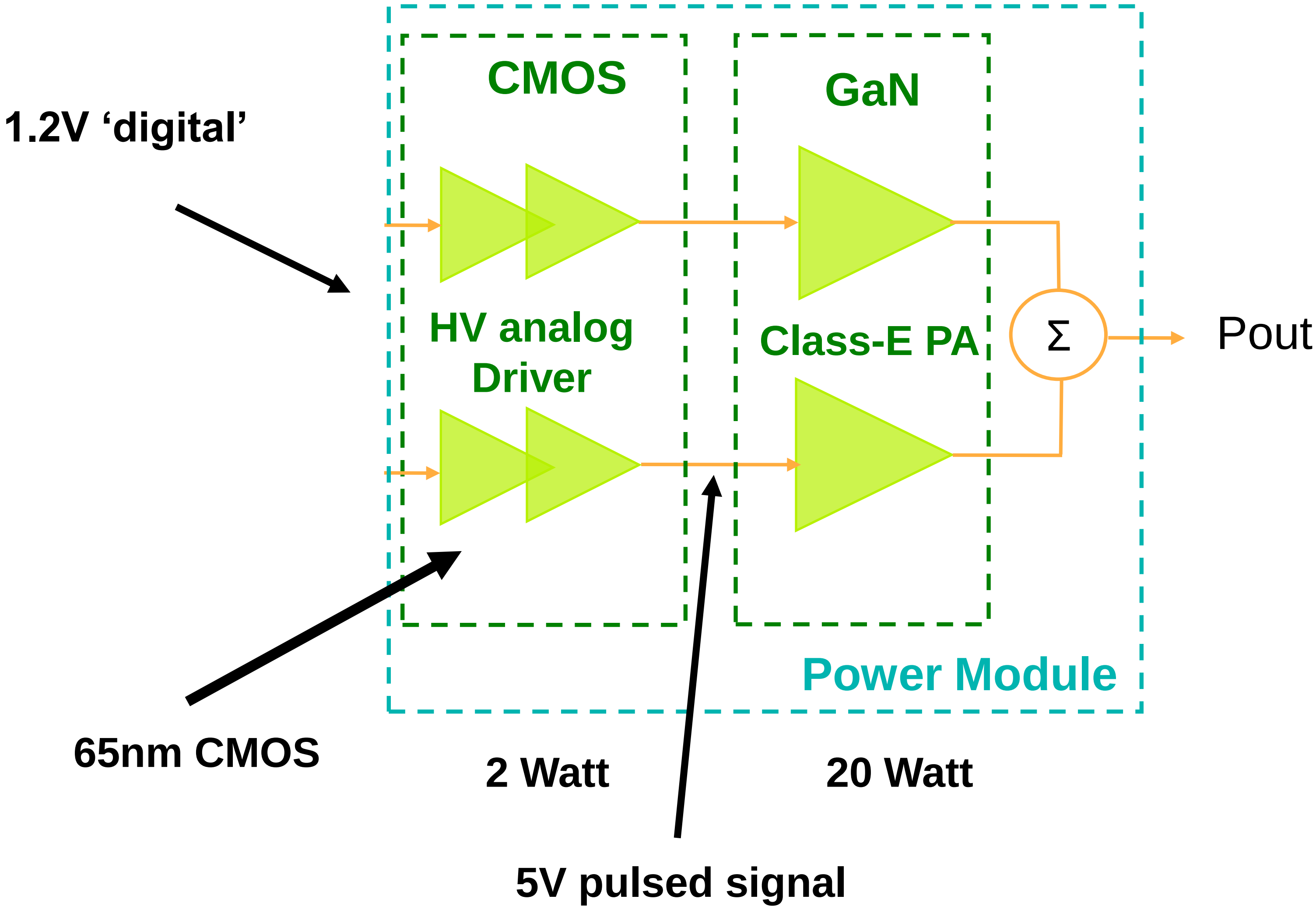


Some examples: BS PA

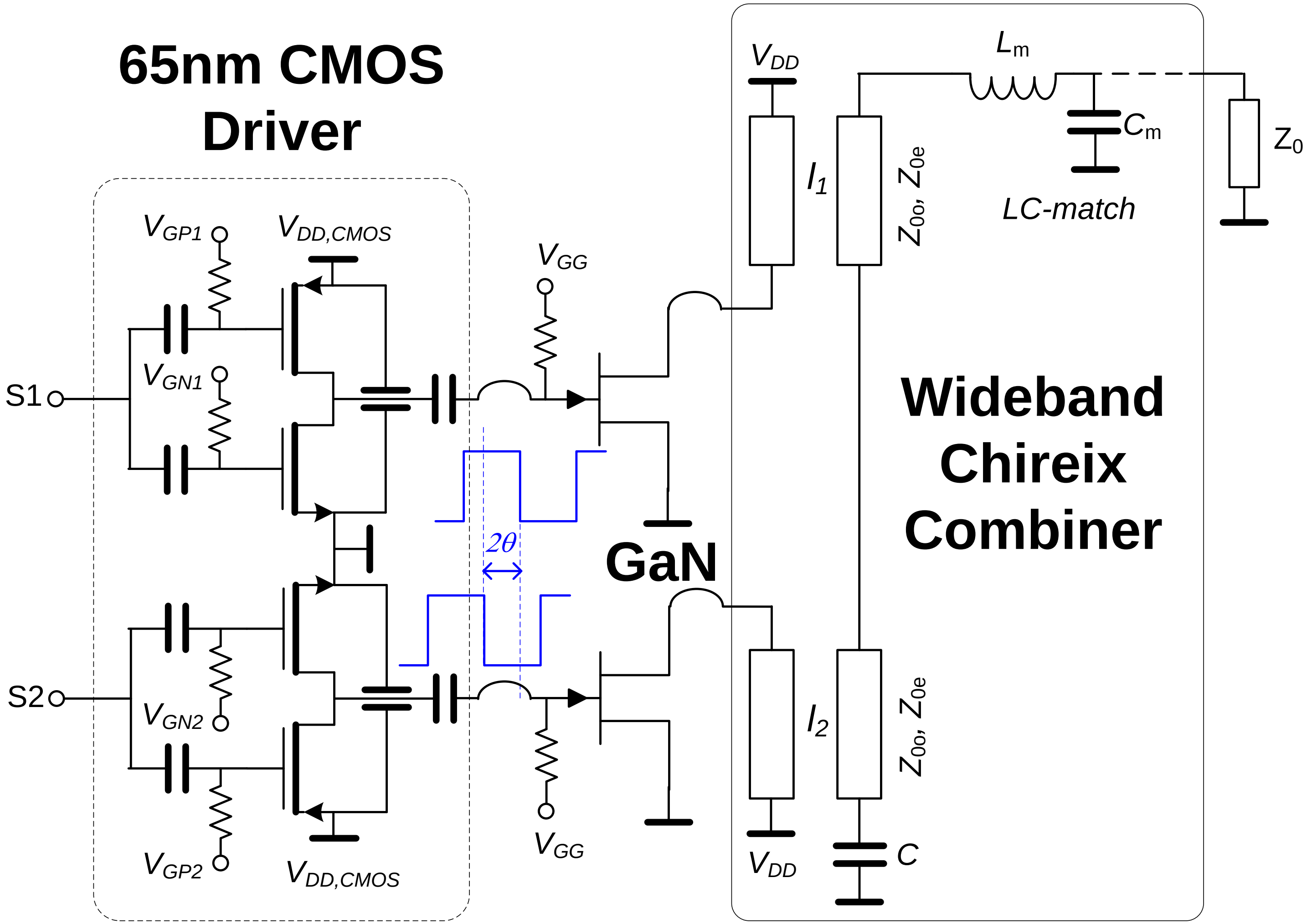


out phasing architecture

Some examples: BS PA

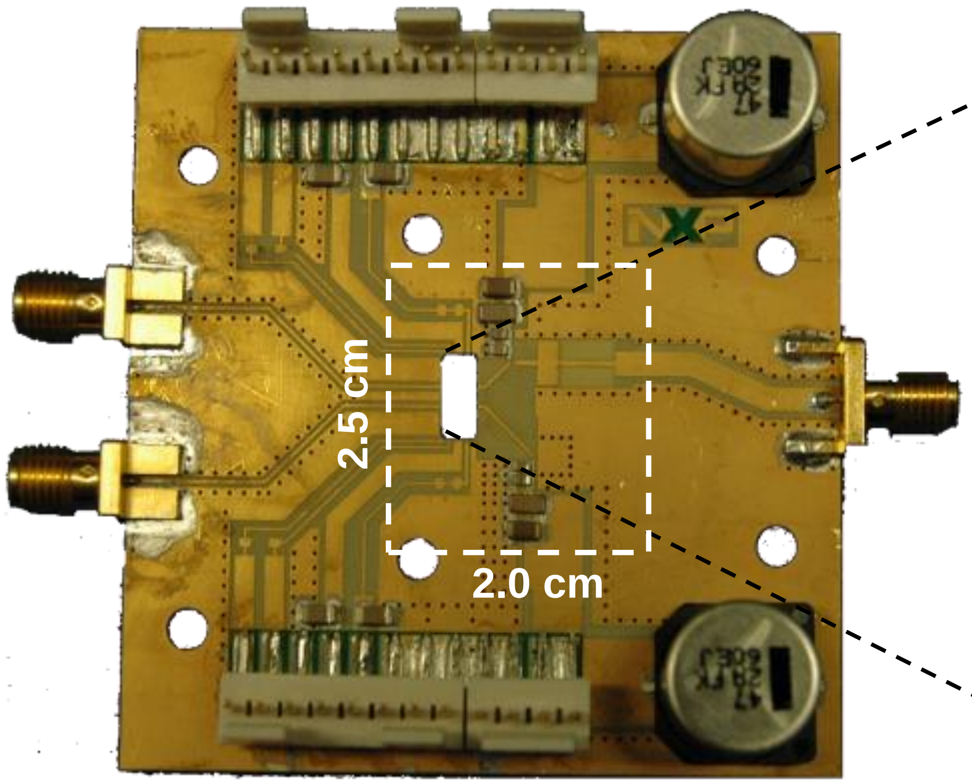


Class-E Out-phasing PA

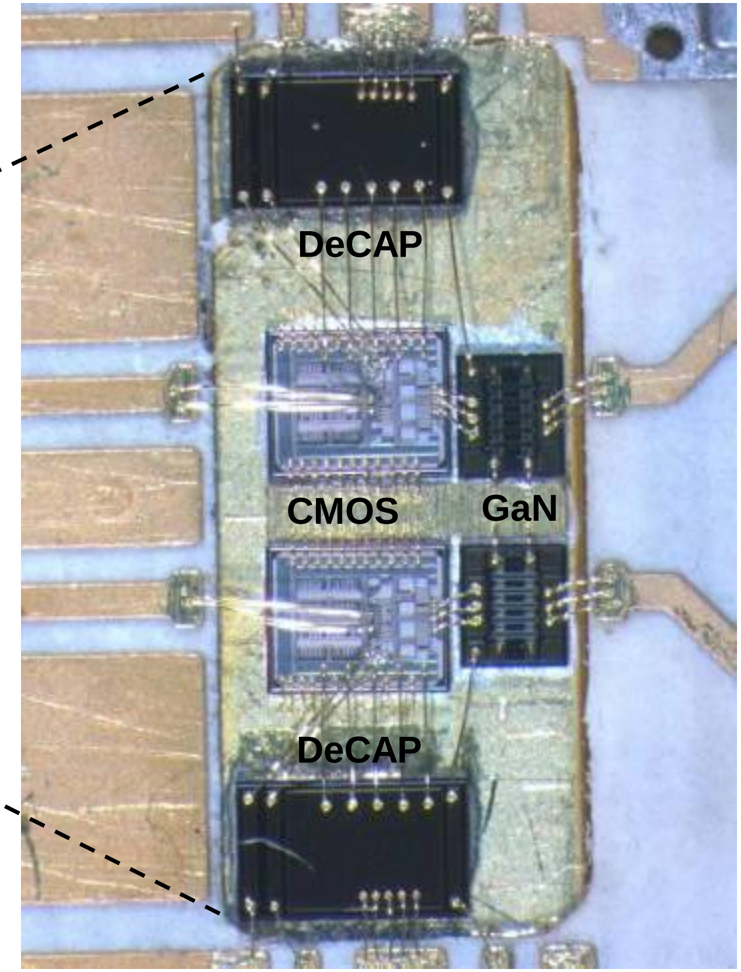


Some examples: BS PA

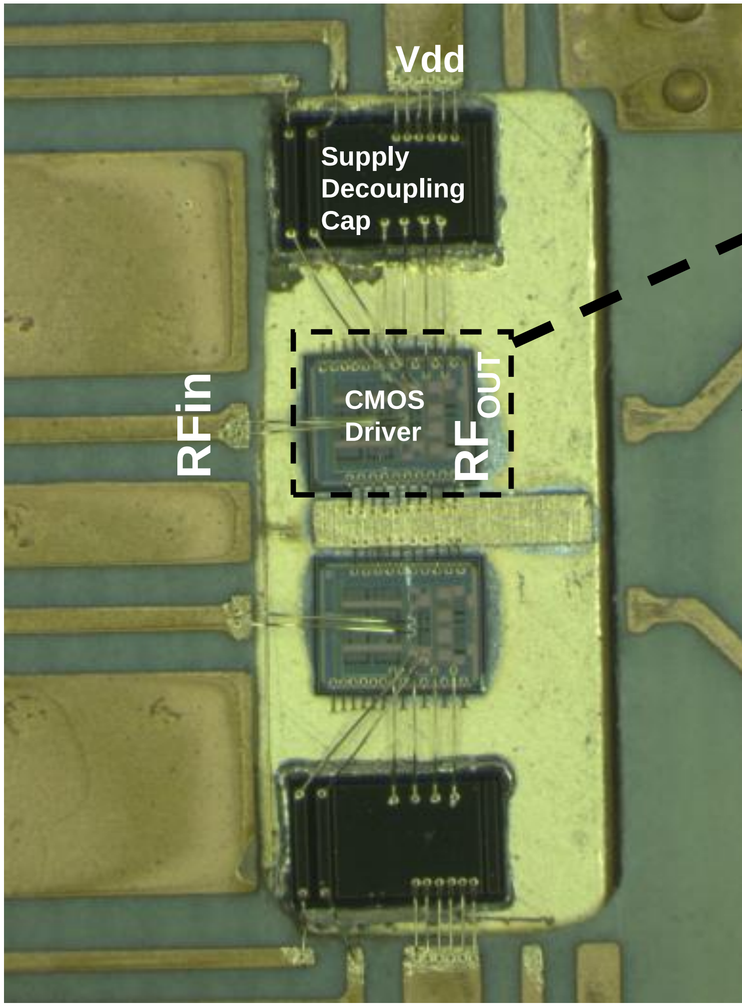
20W Out-phasing PA Line-up (CMOS + GaN)

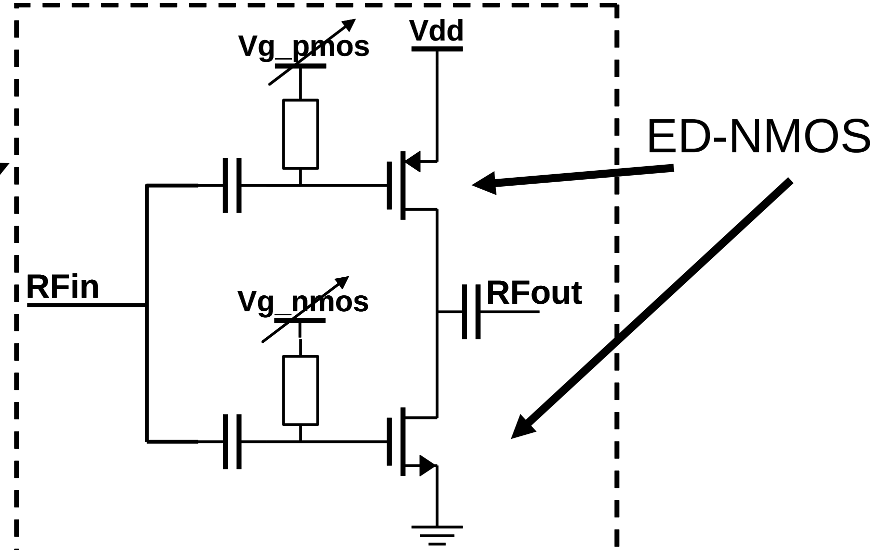


PA line up + matching: 5 cm^2



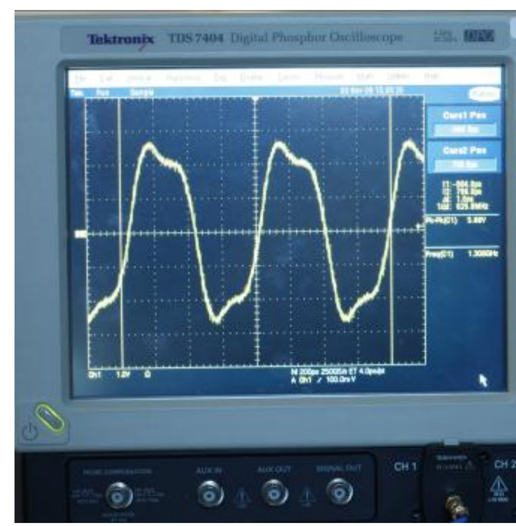
Some examples: BS PA



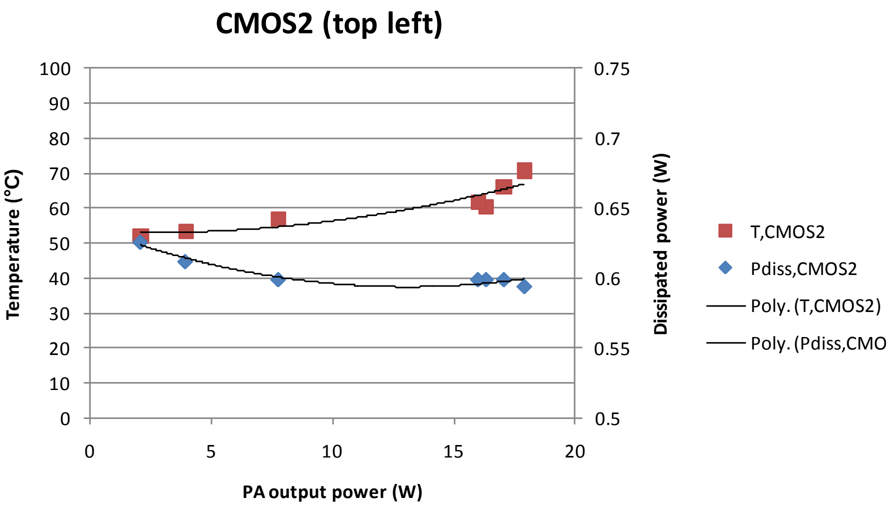


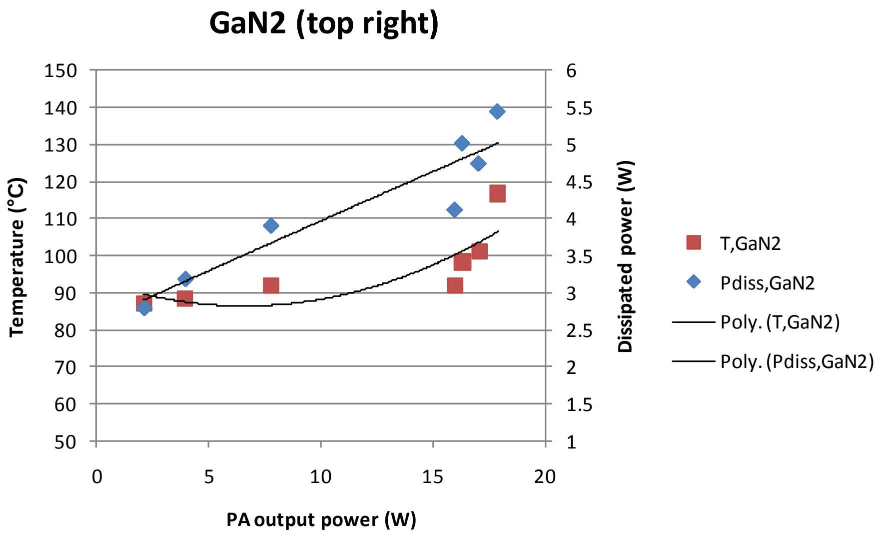
Simplified schematic

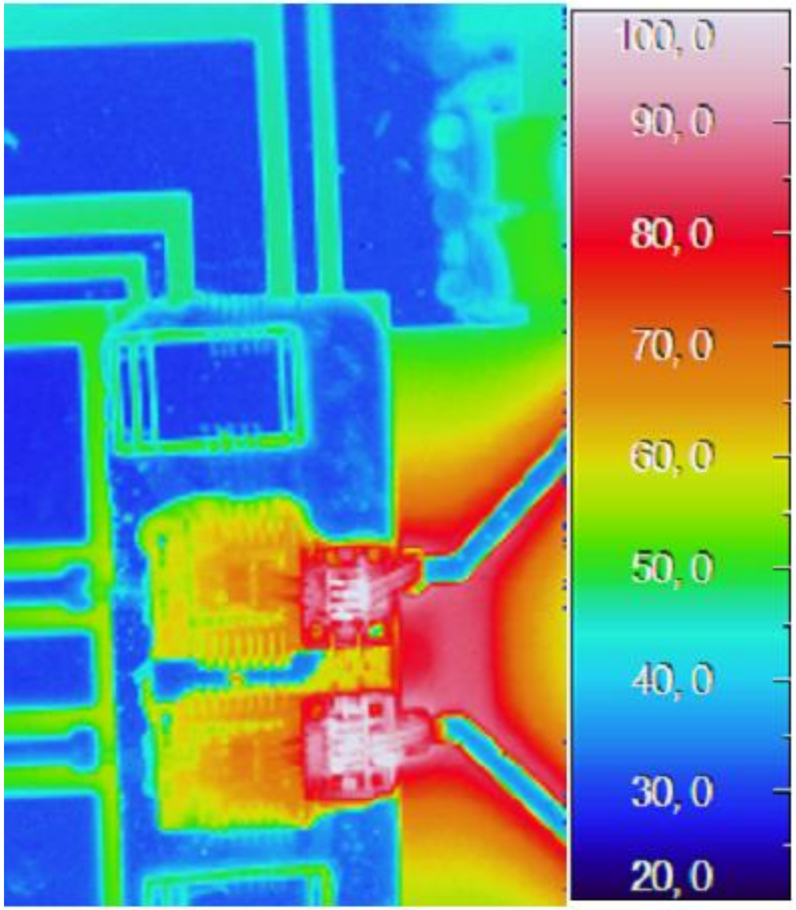
directly 50Ω



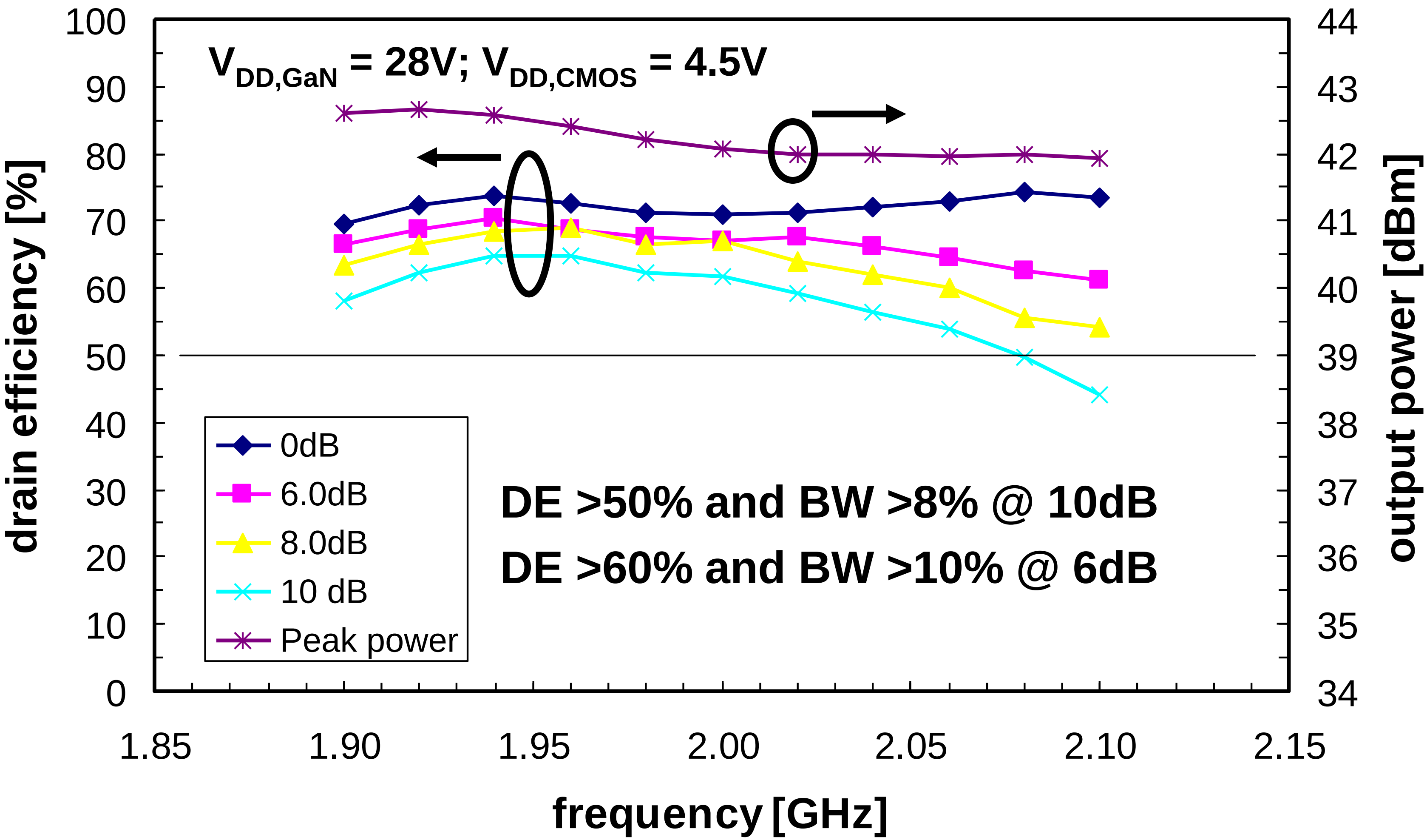
Temperature gradients



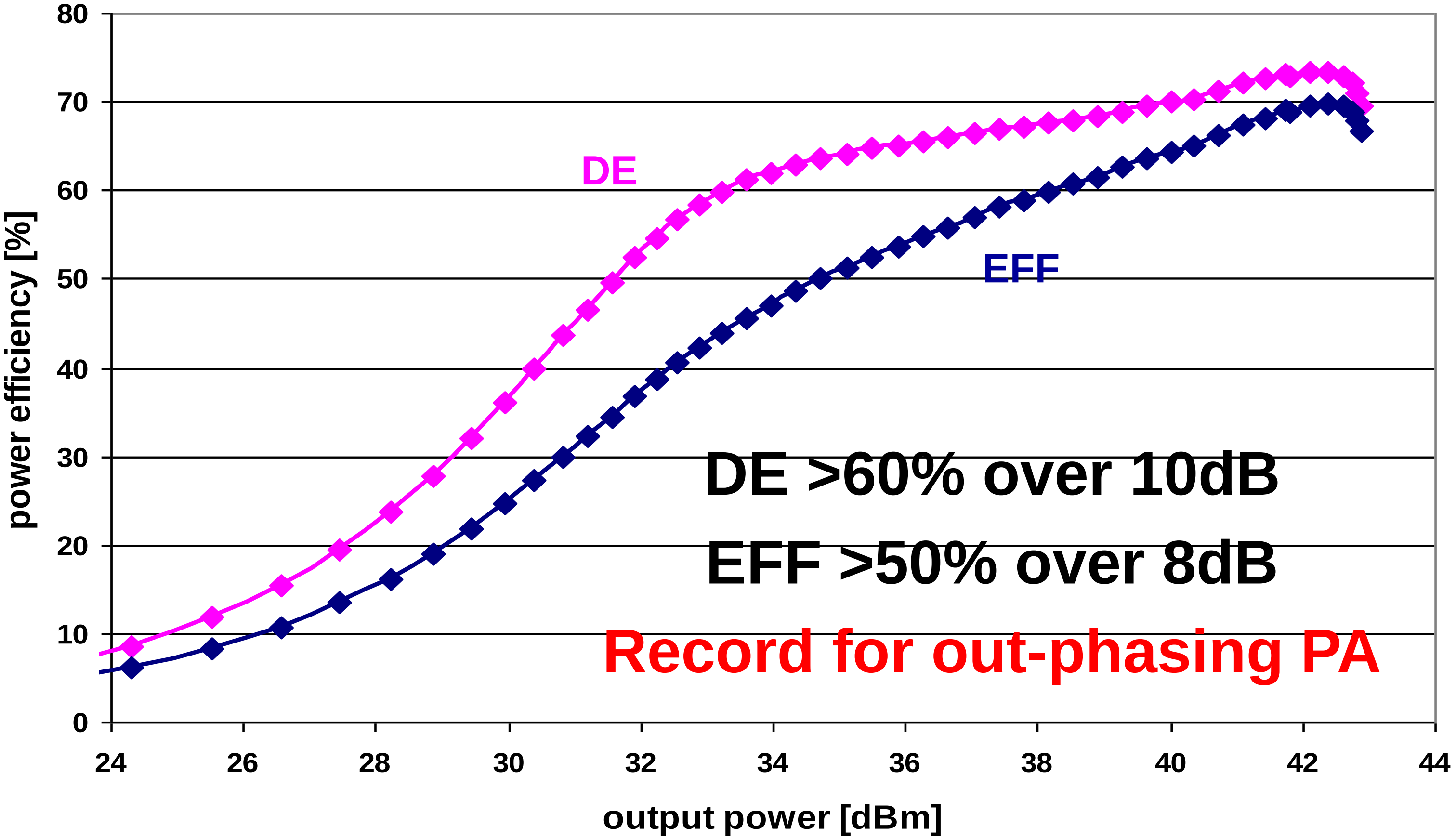




Some examples: BS PA



Some examples: BS PA



Concluding remarks

- Wireless infrastructure IP dominated by compound technology, and for a reason!
- Modern Si-based technologies offer good RF performances, but still less than pHEMT technology
- Combination of improved architectures / circuits and Si-technology might lead to pHEMT replacement in wireless infrastructure

Quest for High Peformance RF

Acknowledgement

- Team members RF ADT @ NXP
- N. Pulsford, N. Kramer, M. Geurts (NXP)