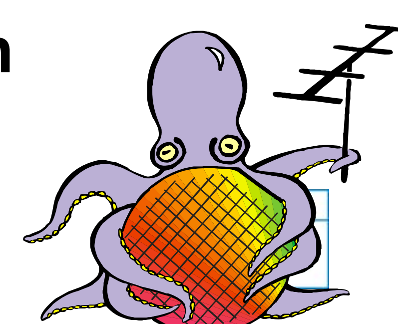
WiMedia Ultra-Wide band Communication

Domine Leenaerts, NXP Research

domine.leenaerts@nxp.com



The Early Days (1998 – 2002)

FCC and the Multi-band OFDM Alliance

The beginning

- September 1998: Notice of Inquiry by FCC
  - Intention to open the spectrum from 3.1 – 10.6GHz for commercial usage
  - Handheld emission mask: -41.3dBm/MHz
  - Minimum channel bandwidth: 500MHz

- May 2000: Notice of proposed rulemaking by FCC
  - Over 900 documents on record
  - Government, academia and industry
  - Characterized interaction mechanism and measured thresholds for impact of UWB signals on government and commercial systems

Why was industry interested in the first place?

- The quest for higher data rate is linked to the search for more bandwidth
  - 7GHz bandwidth ‘for free’
- A ‘quick and dirty’ calculation:

500MHz BW + 1b/Hz/s coding = 500Mb/s data rate

W-USB v2.0

February 14, 2002: official start of UWB

FCC NEWS

Federal Communications Commission
445 12th Street, S.W.
Washington, D.C. 20554

News media information 202 / 418-0500
TTY: 1-888-835-5322
Internet: http://www.fcc.gov
ftp.fcc.gov

This is an unofficial announcement of Commission action. Release of the full text of a Commission order constitutes official action. See MCI v. FCC. 515 F 2d 385 (D.C. Circ 1974).

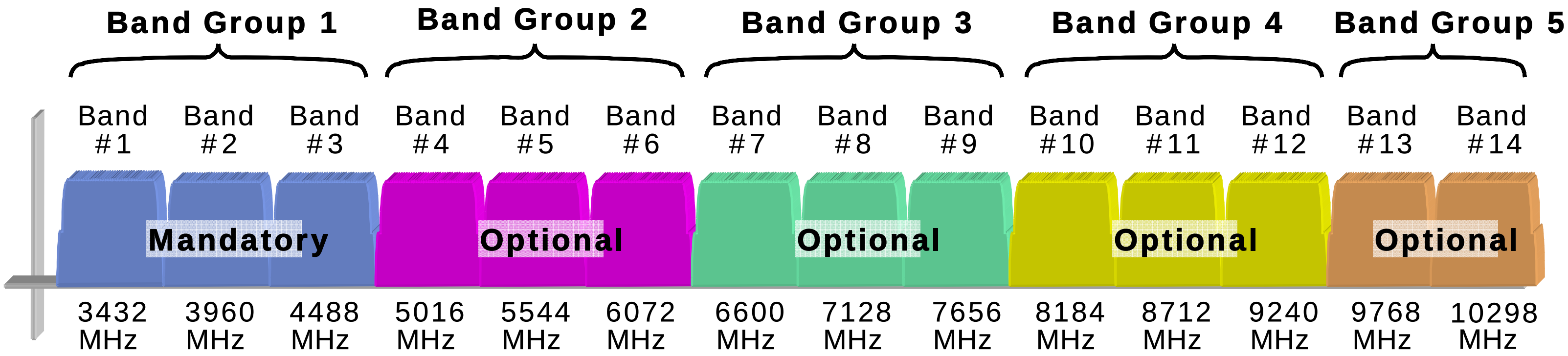
FOR IMMEDIATE RELEASE
February 14, 2002

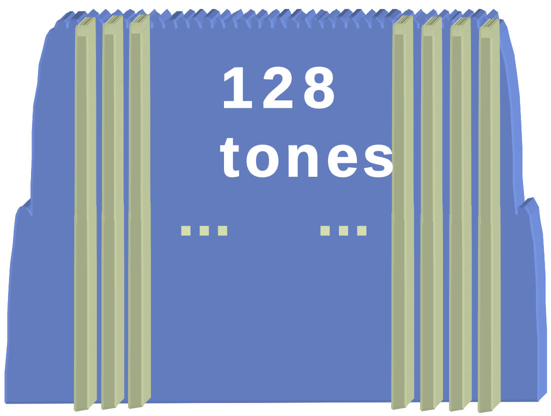
NEWS MEDIA CONTACT:
David Fiske at (202) 418-0513

NEW PUBLIC SAFETY APPLICATIONS AND BROADBAND INTERNET ACCESS AMONG USES ENVISIONED BY FCC AUTHORIZATION OF ULTRA-WIDEBAND TECHNOLOGY

Washington, D.C. – The Federal Communication Commission (FCC) adopted today a First Report and Order that permits the marketing and operation of certain types of new products incorporating ultra-wideband ("UWB") technology. UWB technology holds great promise for a vast array of new applications that have the potential to provide significant benefits for public safety, businesses and consumers in a variety of applications such as radar imaging of objects buried under the ground or behind walls and short-range, high-speed data transmissions.

June 2003: Multi-band OFDM Alliance: MBOA





Channel Number	Band Group 1 Length 6 TFC					
1	1	2	3	1	2	3
2	1	3	2	1	3	2
3	1	1	2	2	3	3
4	1	1	3	3	2	2

<u>MBOA PHY Specification 1.0</u>

- Band Switching
  - Within Band Set #1
  - 3.168 – 4.752 GHz
- Bands 1, 2 and 3
  - Each occupy 528 MHz
- Band Subcarriers
  - 128 tone OFDM
  - Tone width: 4.125 MHz
  - Tone modulation: QPSK

Global Solution: Flexible band plan and use of OFDM subcarriers allows for “spectrum shaping” which can be used to meet worldwide regulatory requirements

Who was MBOA?

Authors

alereon, femto Devices Inc., FOCUS enhancements, GENERAL ATOMICS, Institute for Infocomm Research, intel, MITSUBISHI ELECTRIC, Panasonic, PHILIPS, SAMSUNG ELECTRONICS, STACCATO COMMUNICATIONS, ST, TEXAS INSTRUMENTS, UNIVERSITY OF MINNESOTA, wisair

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AboCom, ADAMYA, ADAPTIVE LABS, ADIMOS, Appairent Technologies, arounda, artimi, AGC ASAHI GLASS COMPANY, BLUE7, BROADCOM, CWC Oulu, CETECOM, GTE, ClearComet, Codified Telenumerics, CommStack, CCS, CONCRETE LOGIC, COVENTIVE, CoWare, CYPRESS, denali, ETS, FUJITSU, FURAXA, GENESYS LOGIC, genius, hp invent, HYSIGNALMINERVIAN, Infineon technologies, Innovative Wireless Technologies, Inphi, INVISIBLE COMPUTER COMPANY, JAALAA, Inc, LEVITON, LITEPOINT, MAXIM, MCCI, mesh dynamics, MEWTEL, Microsoft, Multirate Systems, mindready, NEC Electronics, Netac, NewLogic, NOKIA, OLYMPUS, OPEN INTERFACE, oxygen, Positive Edge ASICs Inc, Prancer.com, Telr@, RadioPulse, Raritan, REALTEK Realtek Semiconductor Corp., RENESAS, RFD, RF MICRO DEVICES, SHARP, Sipex, siworks, stonestreet one, String logix, SVC WIRELESS, SYNOPSYS, TCE, TDK, TeleGateway, TimeDerivative, TOSHIBA, TRDA, TrellisWare Technologies, TTPCOM, TÜV Rheinland of North America, tzero, UnWired Connect, UWB Wireless, vabric, Verisity, VESTEL, VIA Networking Technologies, Inc., VIRAGE LOGIC, WiLAN, WIPRO, Wireless Experience, Wisme, WiQuest, wpans, ZyDAS

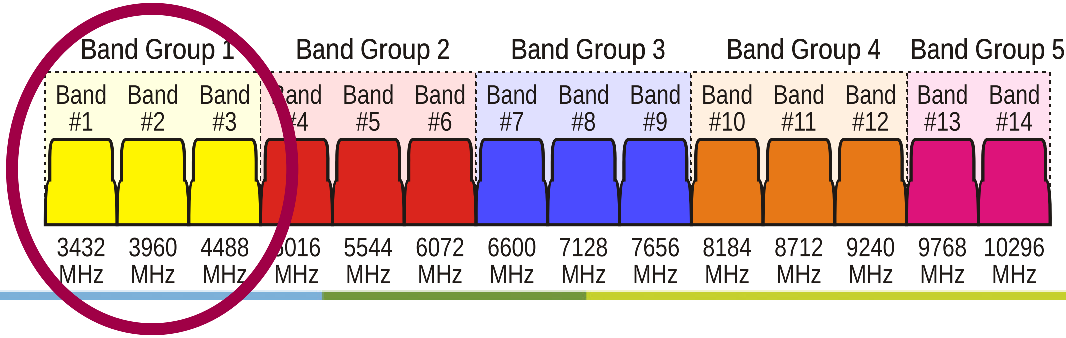
The SiGe era (2003 – 2004)

How to design broadband RF/IF

Q3 2002: Kick-off UWB activity in Philips Research

- General questions
  - How to design broadband at RF and IF?
  - How to solve the LO generation?
  - What architecture is favorable?
  - …

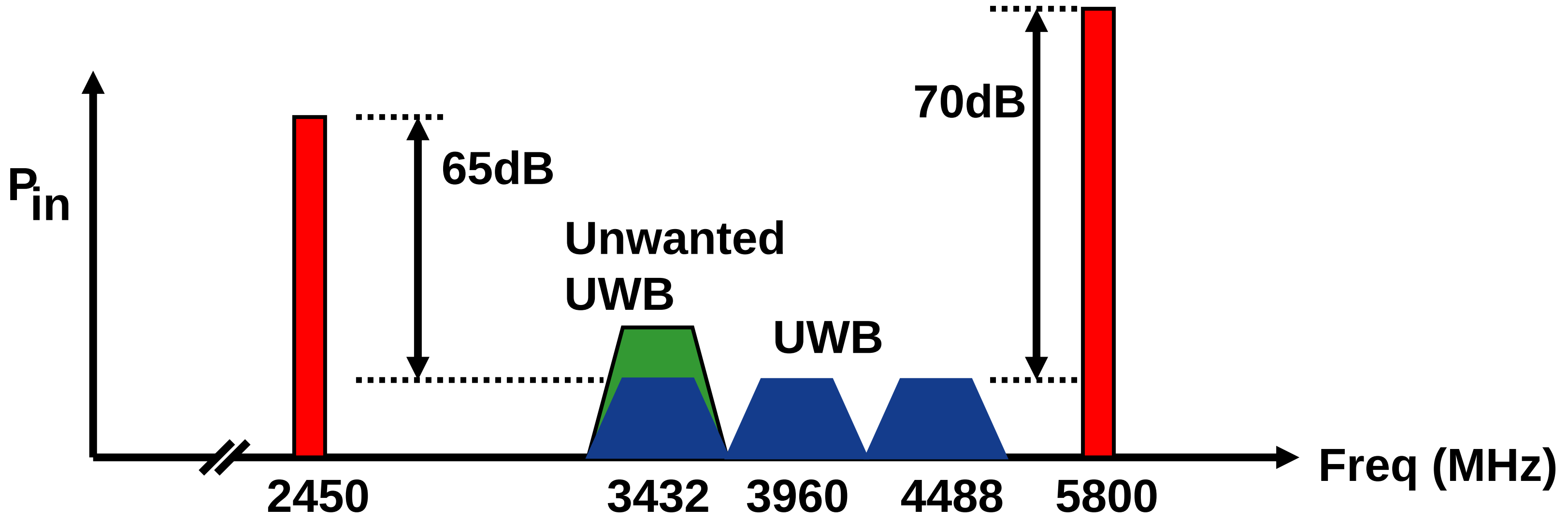
- Additional requirements
  - Use a single RF I/O pin
  - Laptop environment
  - Band Group 1 only!



What were the research challenges?

- This is broadband design!
  - At RF:1.5GHz bandwidth @ 3960MHz (38%)
    - GSM: 50MHz @ 900MHz (6%)
    - WLAN: 200MHz @ 5.25GHz (3.8%)
  - At baseband: 0 – 264MHz
    - GSM: 0 – 100kHz
    - WLAN: 0 – 10MHz
- Very fast frequency hopping: 9.5ns
  - Bluetooth: 200μs
- Linearity and noise are very important!
  - Laptop environment!

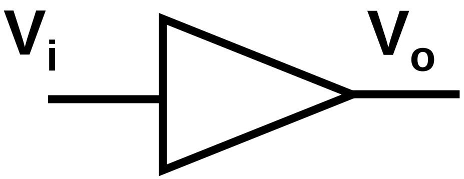
Why is laptop environment an issue?



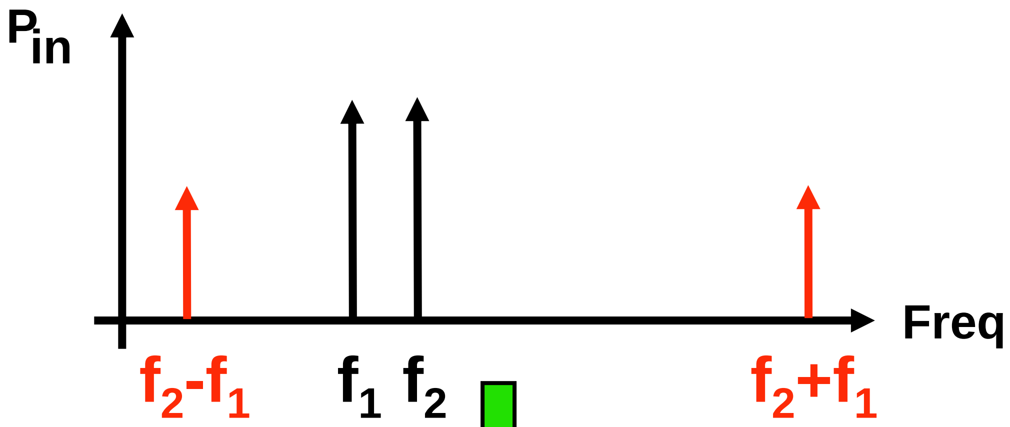
Interferer scenario: (MBOA recommendation)

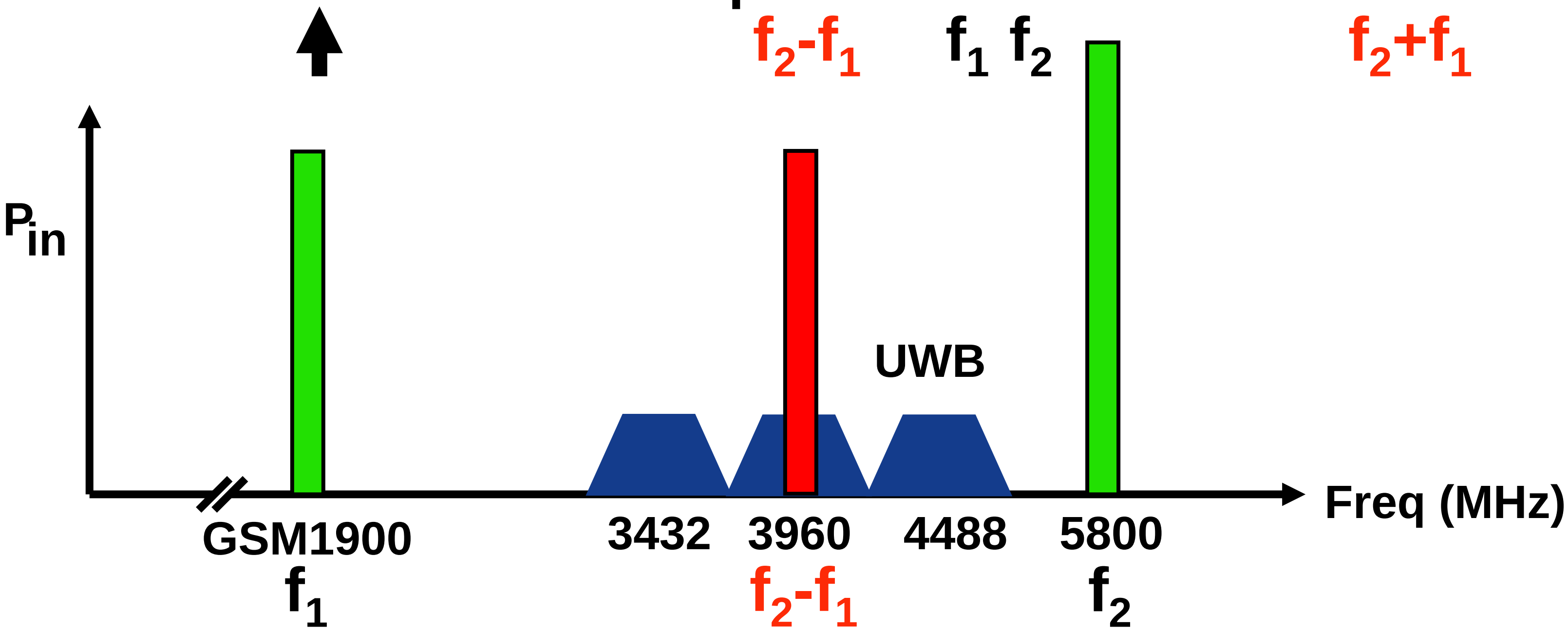
• Distance wanted UWB :	10.0m	→	-73 dBm
• Distance WLAN interferer:	0.2m	→	-3 dBm
• Distance 2.4GHz ISM interferer:	0.2m	→	-8 dBm
• Distance GSM1900 interferer:	1.0m	→	-8 dBm
• Distance unwanted UWB interferer:	2.0m	→	-60 dBm

Out-of-band interferers demand high linearity

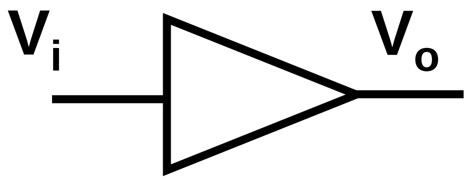


$$V_o = GV_i + \alpha V_i^2 + \beta V_i^3$$

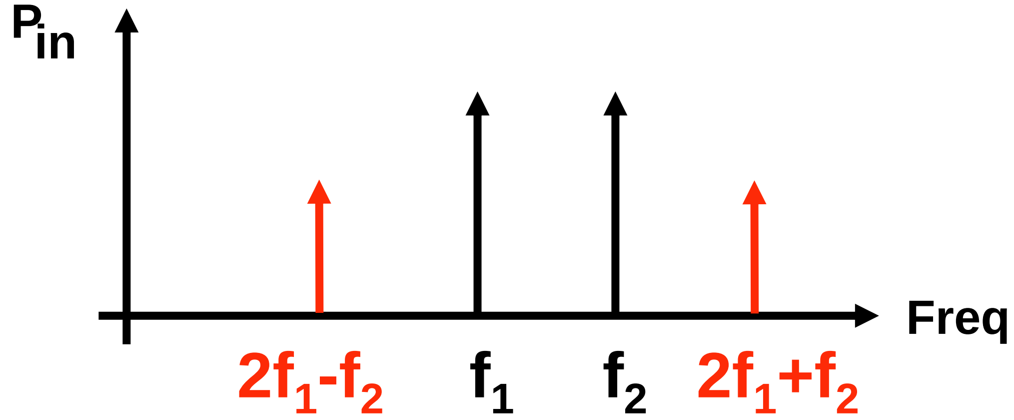


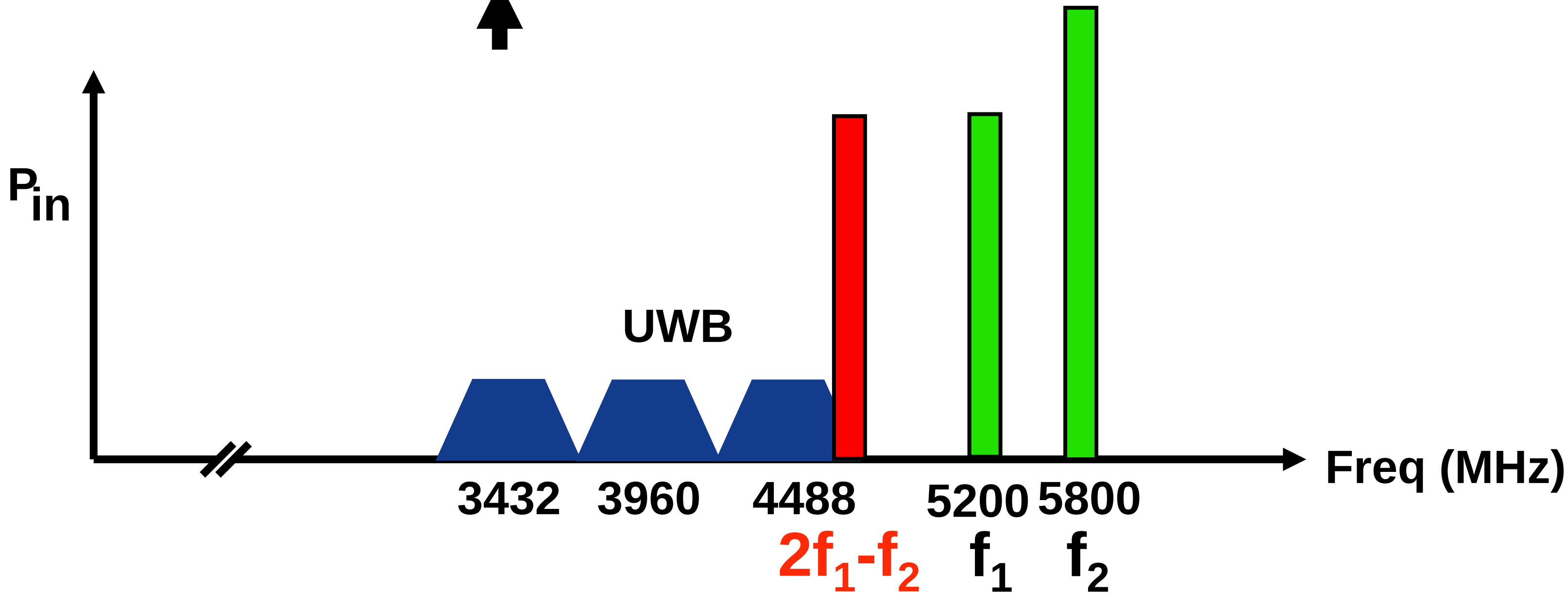


Out-of-band interferers demand high linearity

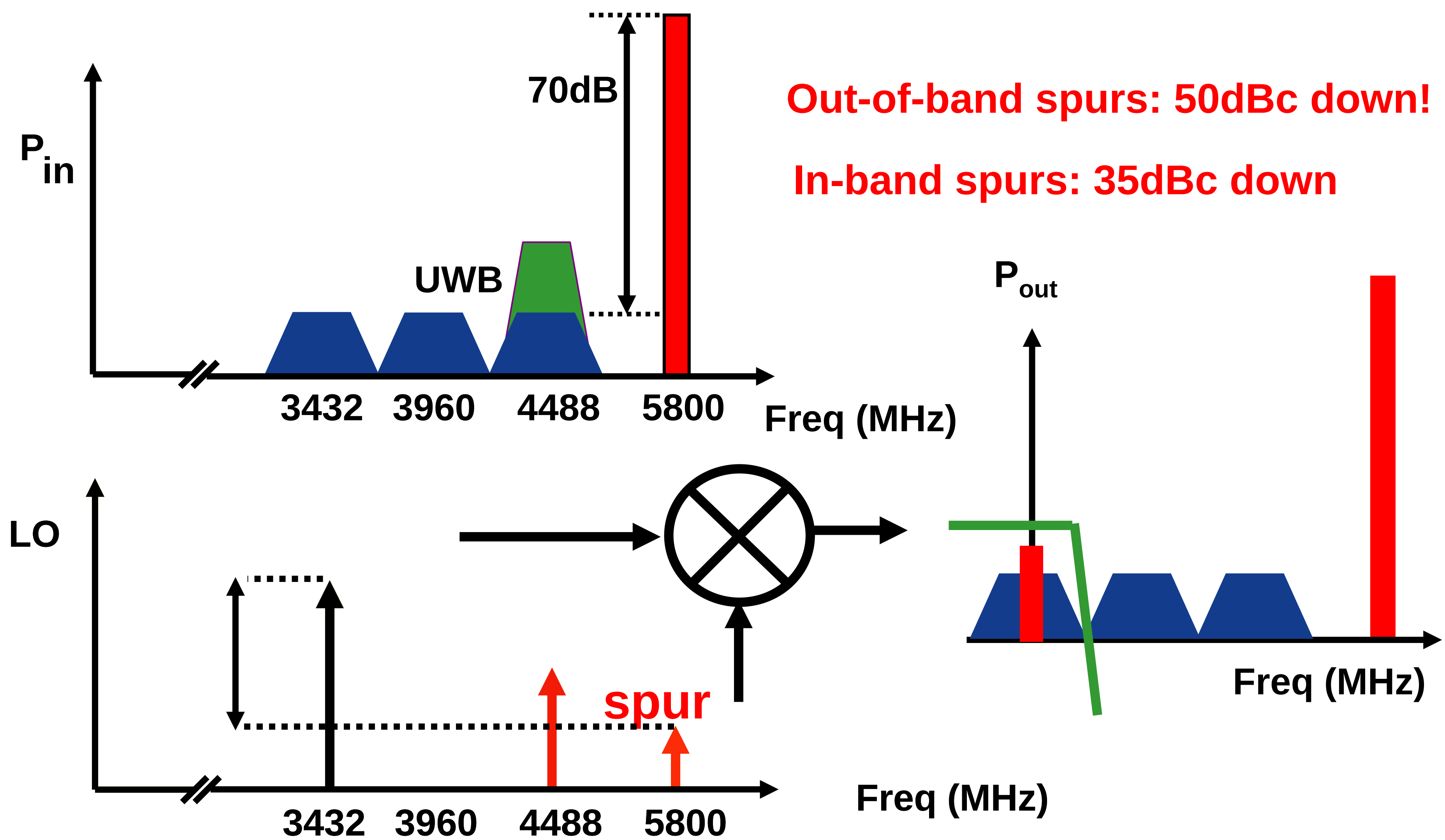


$$V_o = GV_i + \alpha V_i^2 + \beta V_i^3$$





Out-of-band interferers demand low spurs



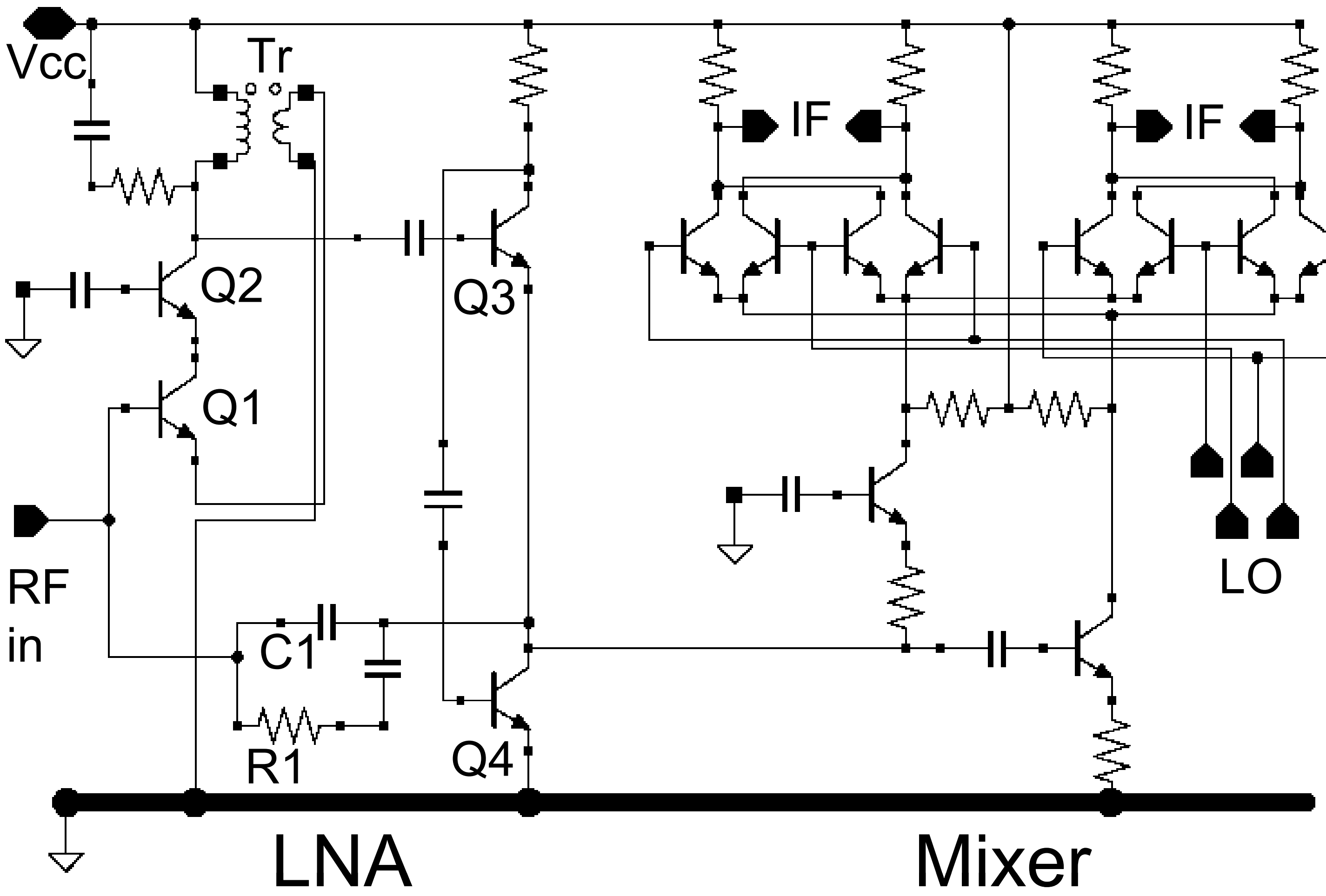
The choice of technology for the radio

- SiGe BiCMOS was the clear choice
  - 180nm CMOS was available but clearly not performing well above 5GHz
  - Time-to-market

- All the early adopters started in SiGe
  - Staccato, Wisair, Alereon, …

- But we envisioned that future CMOS processes would do the job
  - Ph.D candidate at UTwente to explore broadband design techniques in CMOS.

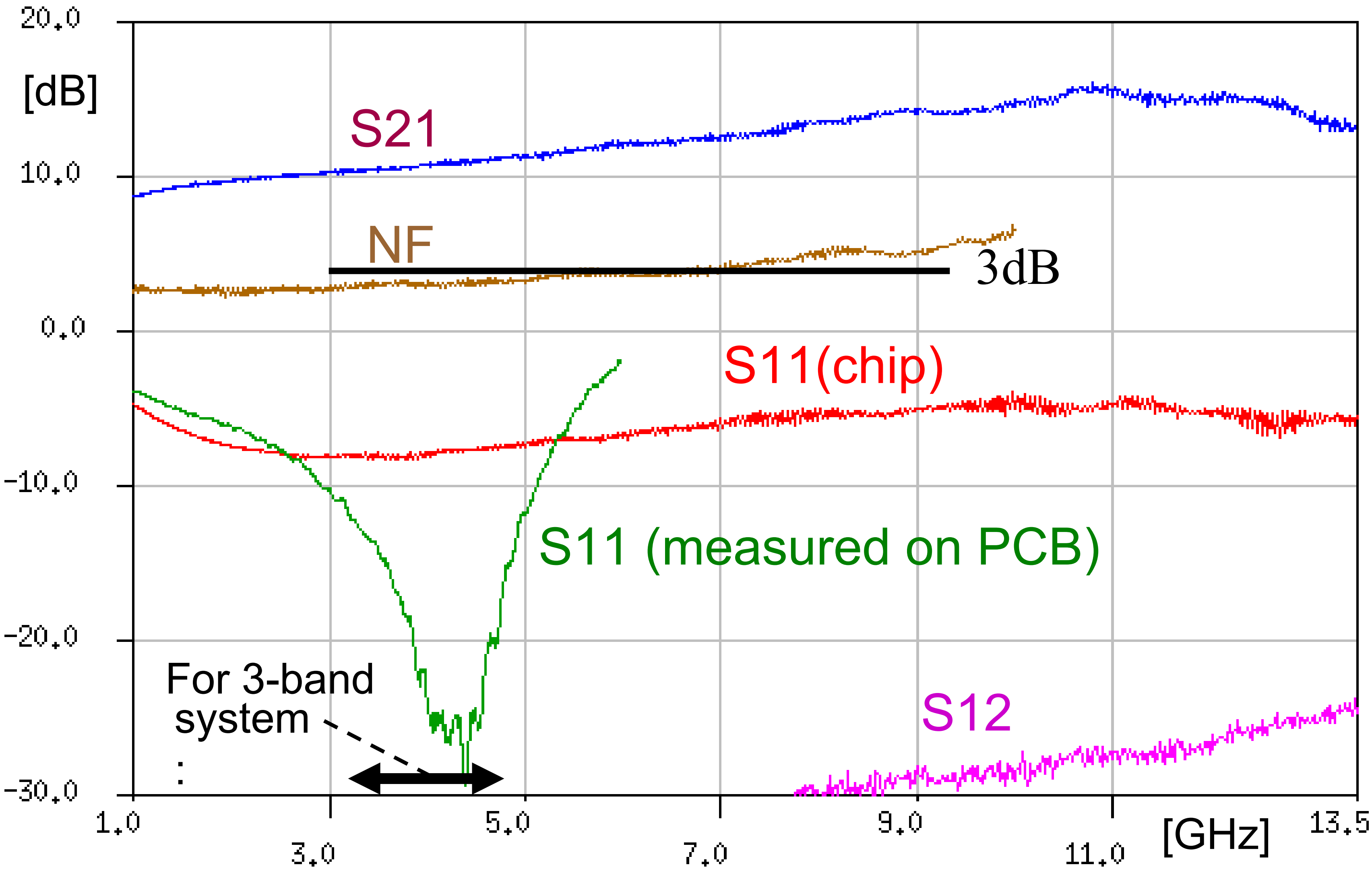
Our solution to broadband design in 2003



Double loop feedback with active balun

[ISSCC2005]

Our solution to broadband design in 2003



Our solution to fast freq. hopping in 2003

- Integer-*N* PLL
  - Max *fref* = GCD(output frequencies) = 528MHz
  - Min lock time ≅ 20 ref. periods ≅ 40ns > 9.5ns
- Fractional-*N* PLL
  - 9.5ns would require f_{ref} ≅ 2.1GHz
  - within 312.5ns, the output would settle to different frequencies several times → spurs
- Use 3 PLLs, one for each frequency
  - Area costly if LC-oscillators, and ring oscillators in BiCMOS are power hungry
  - Frequency pulling

Our solution to fast freq. hopping in 2003

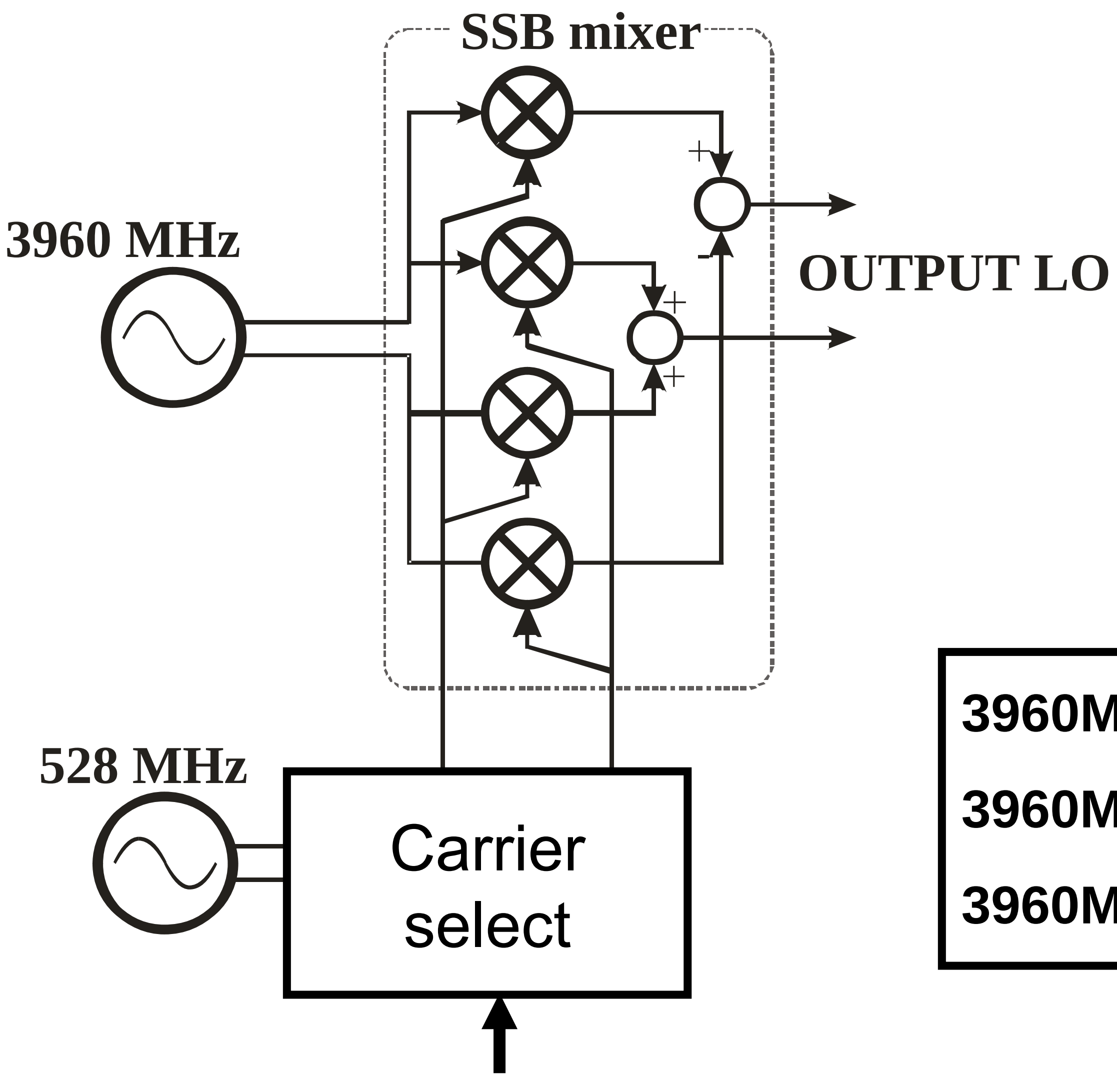
Frequency translation ⇨ Complex multiplication:

$$e^{j2\pi(f+\Delta f)t} = e^{j2\pi\cdot f\cdot t}\cdot e^{j2\pi\cdot\Delta f\cdot t}$$

$$\boldsymbol{f = 3960MHz}$$

$$\boldsymbol{\Delta f = \pm 528MHz}$$

Our solution to fast freq. hopping in 2003



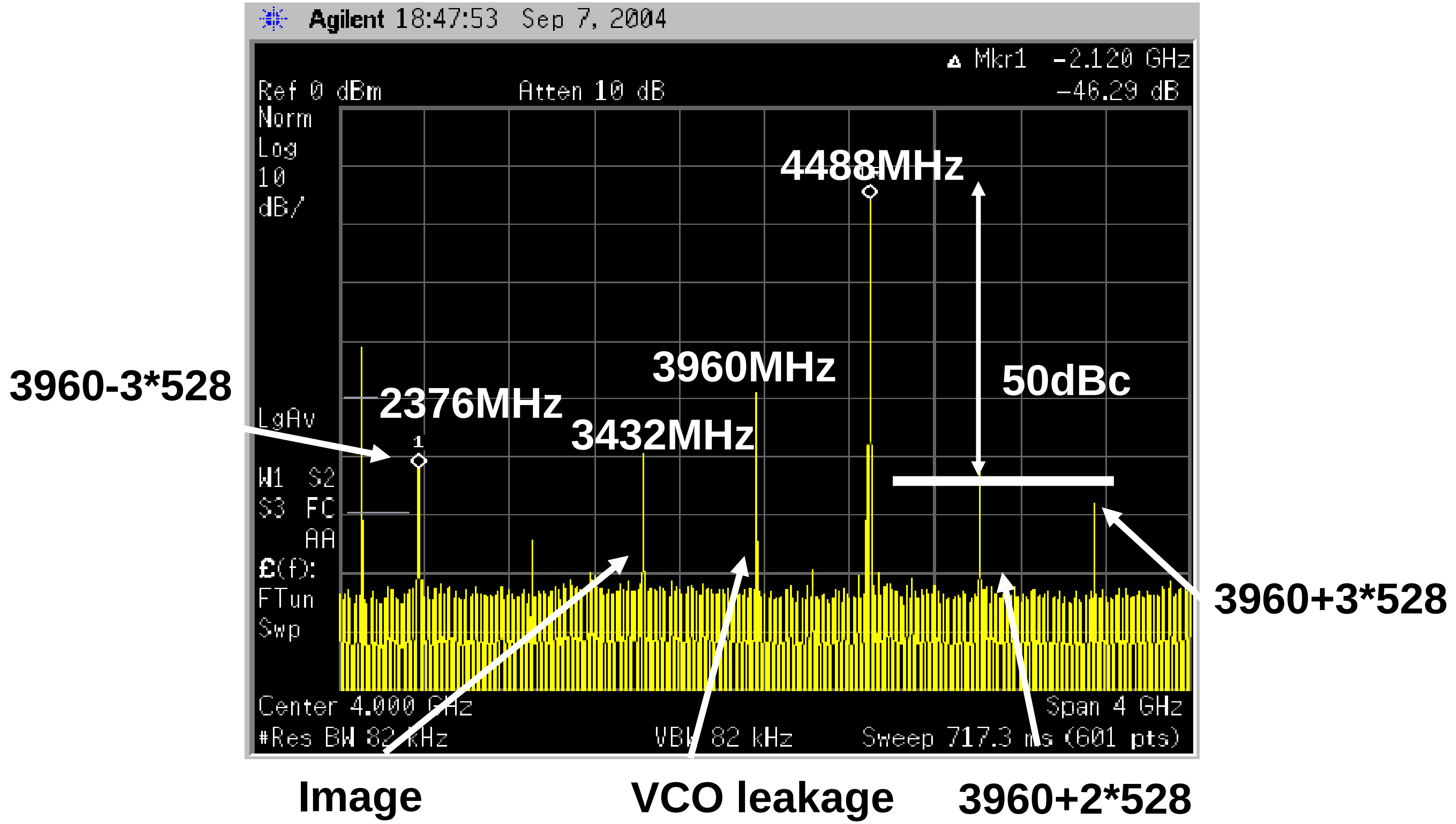
$$I_{out} = I_1 I_2 - Q_1 Q_2$$
$$Q_{out} = I_1 Q_2 + Q_1 I_2$$

3960MHz – 528MHz = 3432MHz

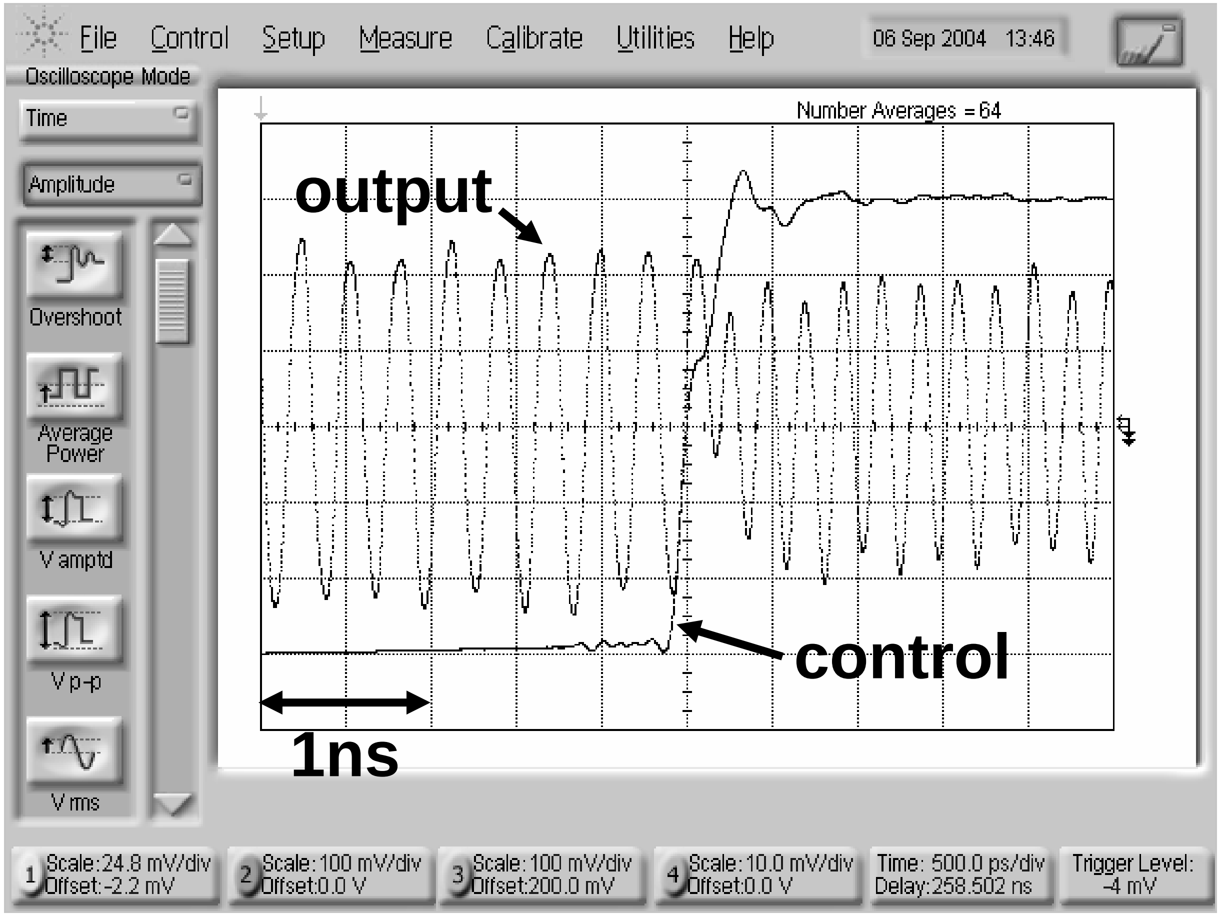
3960MHz + 0MHz = 3960MHz

3960MHz + 528MHz = 4488MHz

Our solution to fast freq. hopping in 2003

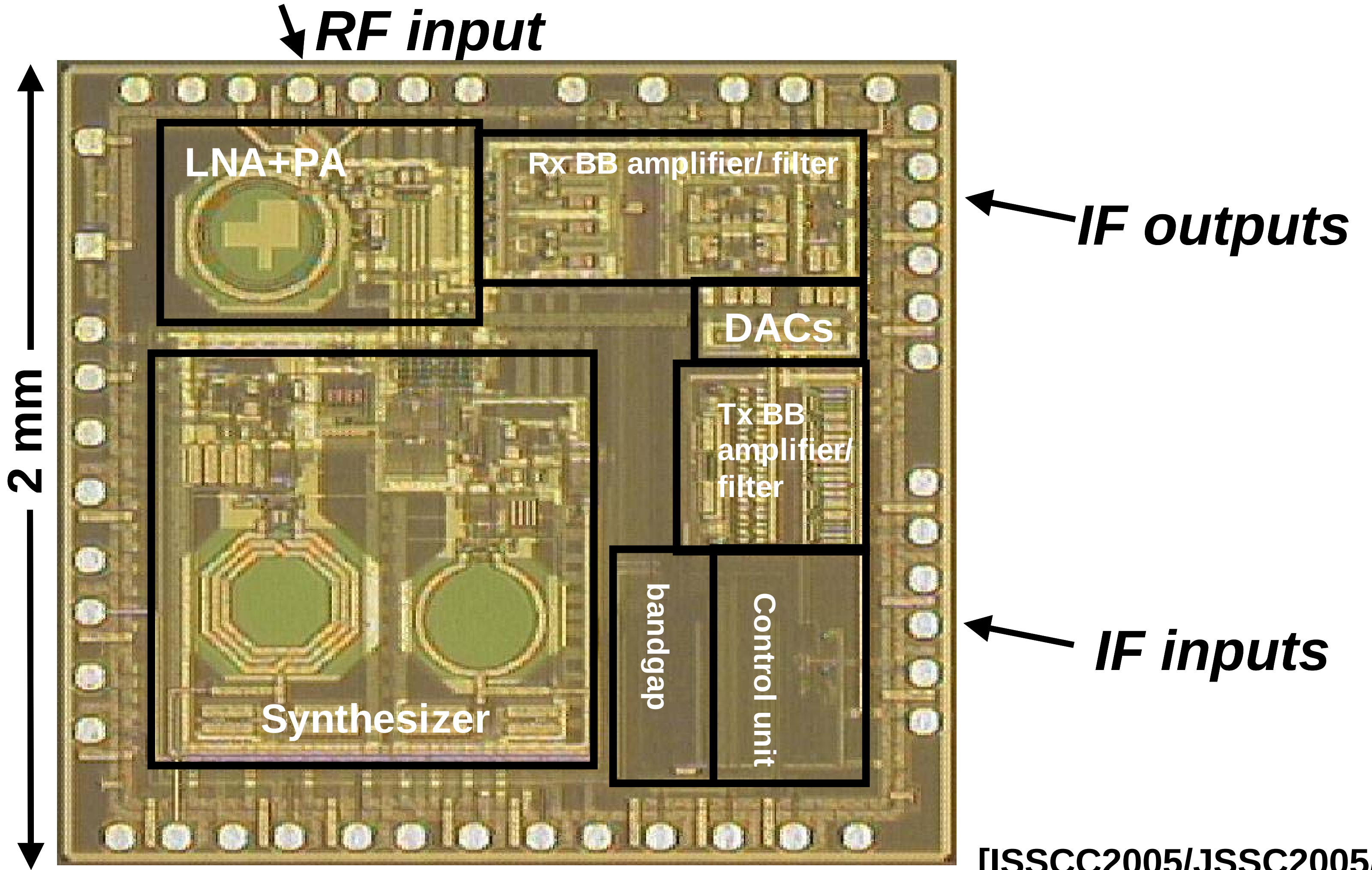


Our solution to fast freq. hopping in 2003



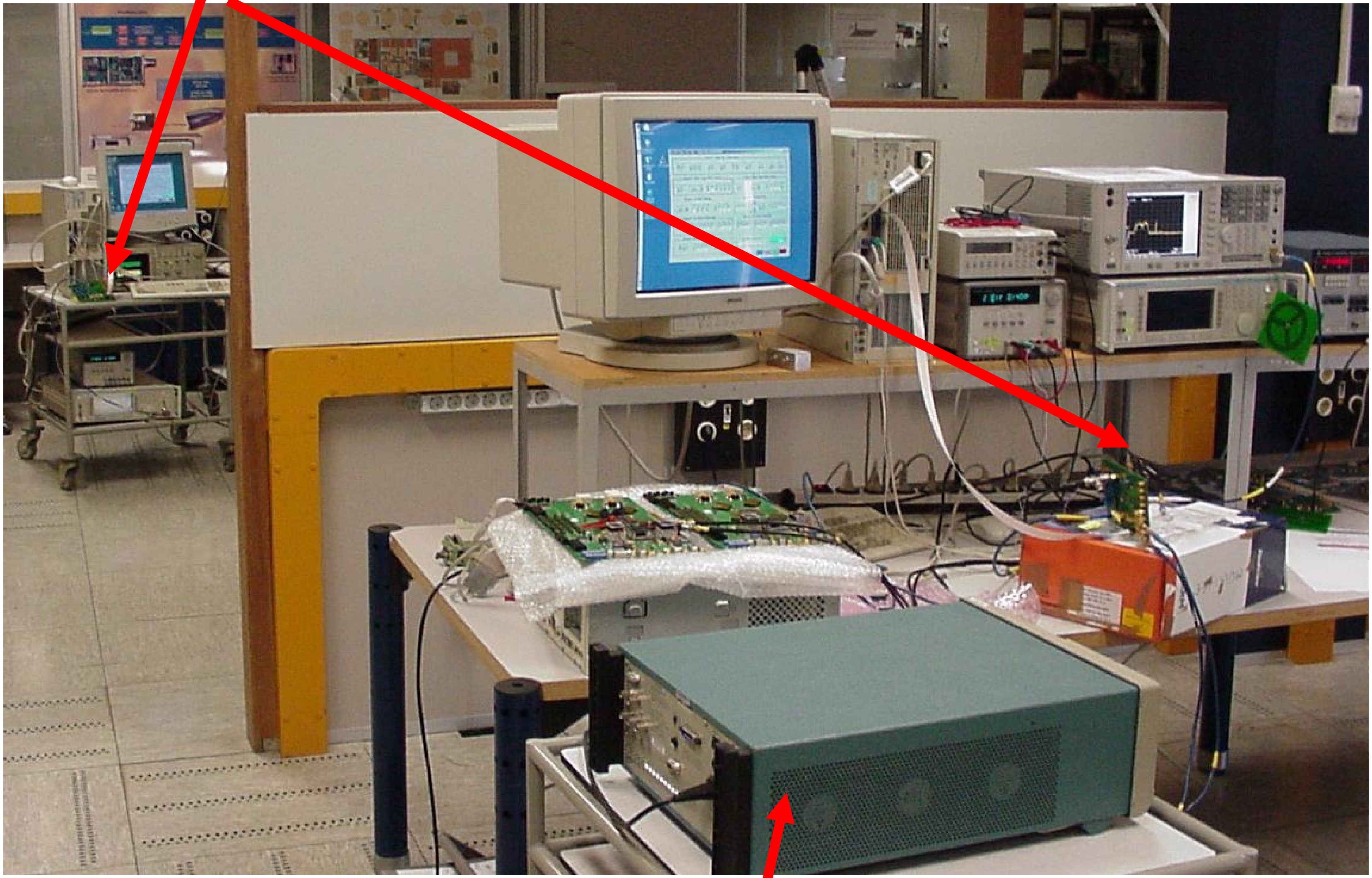
Hopping from band #1 to #3

Our radio in 0.25um SiGe BiCMOS in 2004



[ISSCC2005/JSSC2005/RFIC2006]

Our radio in 0.25um SiGe BiCMOS in 2004

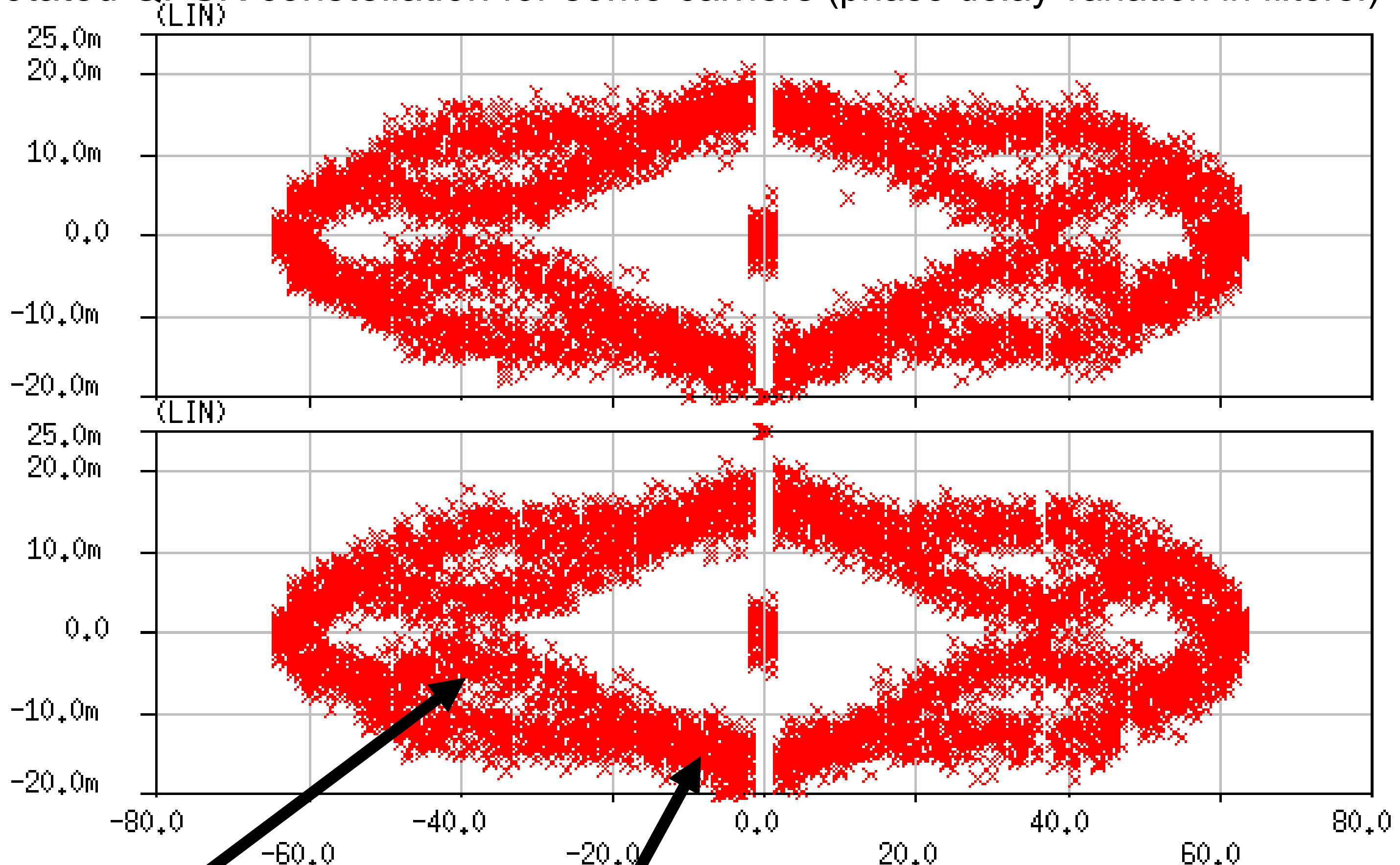


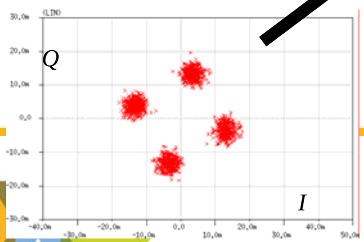
Data source = AWG

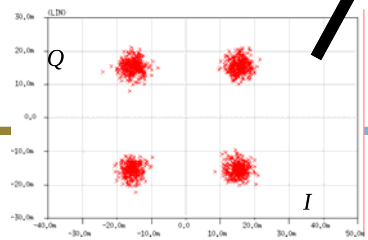
Our radio in 0.25um SiGe BiCMOS in 2004

Loopback mode, output after FFT

Notice rotated QPSK constellation for some carriers (phase delay variation in filters!)







Sub-carrier index (spacing 4.125 MHz)

And what next…..?

- Around 2004 – 2005 deadlock situation in IEEE standardization of IEEE802.15.4a
  - Two camps: MBOA vs. ExtremeSpectrum
- This partly influenced Philips' decision to put UWB activity on hold
- ISSCC2005 showed two things
  - Our SiGe had outstanding NF and linearity performance
  - **You can do it in CMOS!**

	[1]	[2]	[3]	[4]	This work
Technology	0.13μm CMOS	90nm CMOS	0.13μm CMOS	0.18μm CMOS	0.25μm SiGe BiCMOS
NF (dB)	6-7	6.9	4.1	4.7	4.5
iIP3 (dBm)	-15	-16	-22	-0.8	-6
iIP2 (dBm)				+22	+25
EVM (dB)	-19.5	-28	-27	-28.6	-24
P_{out} (dBm)		-3.8	+5	-12.6	-6
TX OIP3		8.6		11.8	12
P diss Rx (mW) Pdiss Tx (mW)	100mA @ 3.3/1.5V 70mA @ 3.3/1.5V	224 131	237 284	412 397	199 190
Chip area (mm^2)	2	4.5	6.6	16	4

[1] Aytur, ISSCC2006
[2] Tanaka, ISSCC2006
[3] Sadner. ISSCC2006
[4] Lo, ISSCC2006

2004 - 2005: WiMedia adopts UWB for w-USB

Dual band group operation in CMOS

May 2004: WiMedia embraces MBOA

WiMEDIA Alliance

The WiMedia Alliance Announces Support for the MultiBand OFDM Alliance UWB Specifications

WiMedia's endorsement of the MBOA ultrawideband specifications enables the realization of a multi-protocol UWB ecosystem

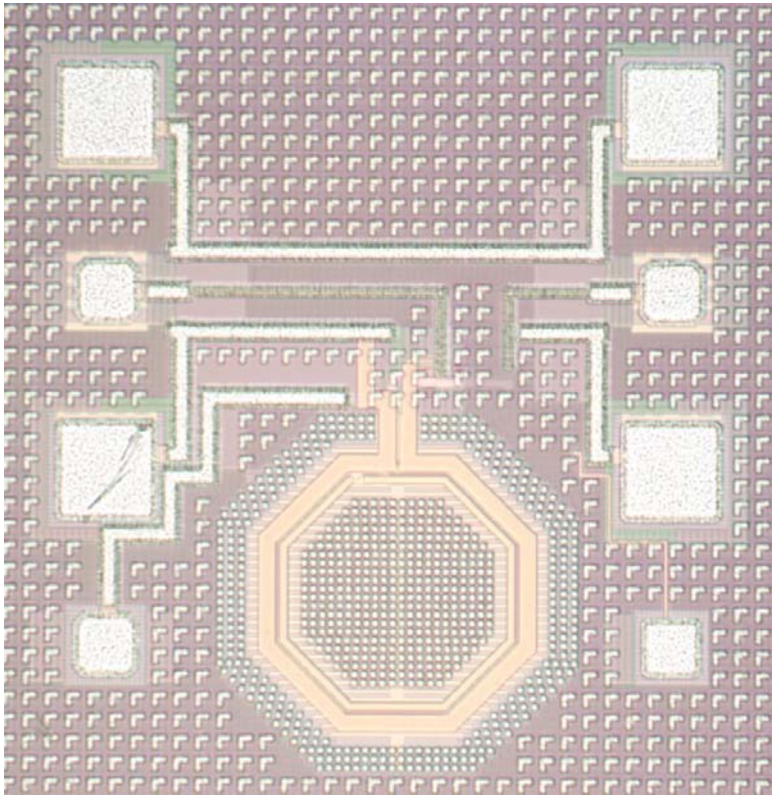
San Ramon, Calif. – May 5, 2004 – The WiMedia Alliance (www.wimedia.org) today announced its endorsement of the MultiBand OFDM Alliance (MBOA) ultrawideband specifications for use with the WiMedia Convergence Platform. This will pave the way for wireless connectivity between electronics products in consumer electronics, PC, and mobile segments. The endorsement pairs the MBOA's (www.multibandofdm.org) efforts to deliver a high data-rate, short-range wireless UWB radio with the convergence architecture being developed by the WiMedia Alliance. The combination provides a foundation for the implementation of wireless versions of 1394, USB, and Internet-Protocol–based application protocols. The WiMedia Convergence Platform allows these diverse protocols to coexist in the same physical location with efficient and fair access to the UWB radio channel.

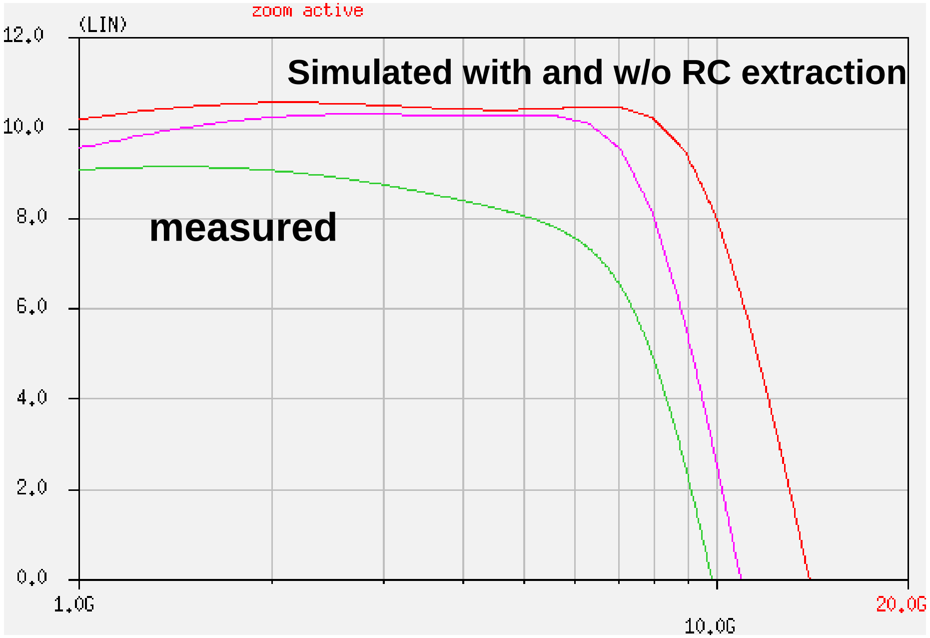
The WiMedia Alliance's mission is to promote wireless connectivity and interoperability among multimedia devices. The initial focus was based on the IEEE 802.15.3 standard and in anticipation of its UWB physical layer extension. The leading contender in this IEEE process is the proposal from the MBOA. However, during the past year, the IEEE has not confirmed the new physical layer prompting WiMedia to take the direct action of endorsing this technical direction.

"The overwhelming industry support for the MBOA, now with more than 100 members, simplified our decision to move forward with this endorsement," said Jim Meyer, WiMedia Board Member. "To provide value to our members, and their customers, the WiMedia Alliance maintains alignment with the companies developing silicon and the end products."

New Challenge: broadband CMOS

- June 2005 first building blocks in 90nm with redesign in October 2005





Linearity performance worse than SiGe

New challenge: dual band group operation

WiMedia Alliance
2400 Camino Ramon, Suite 375
San Ramon, CA 94583 USA
Phone: 925.275.6604
Fax: 925.275.6691

FOR IMMEDIATE RELEASE

Contact: Lauren Stilwell
WiMedia Alliance PR
(503) 297-5090
pr@wimedia.org

ECMA INTERNATIONAL RELEASES UWB STANDARD BASED ON WIMEDIA UWB RADIO PLATFORM

SAN RAMON, Calif.—December 8, 2005—The WiMedia Alliance today announced that Ecma International's newly released standard for UWB technology is based on the WiMedia Ultra-Wideband (UWB) Common Radio Platform. Ecma will submit the standard to ISO/IEC JTC 1 for fast track approval.

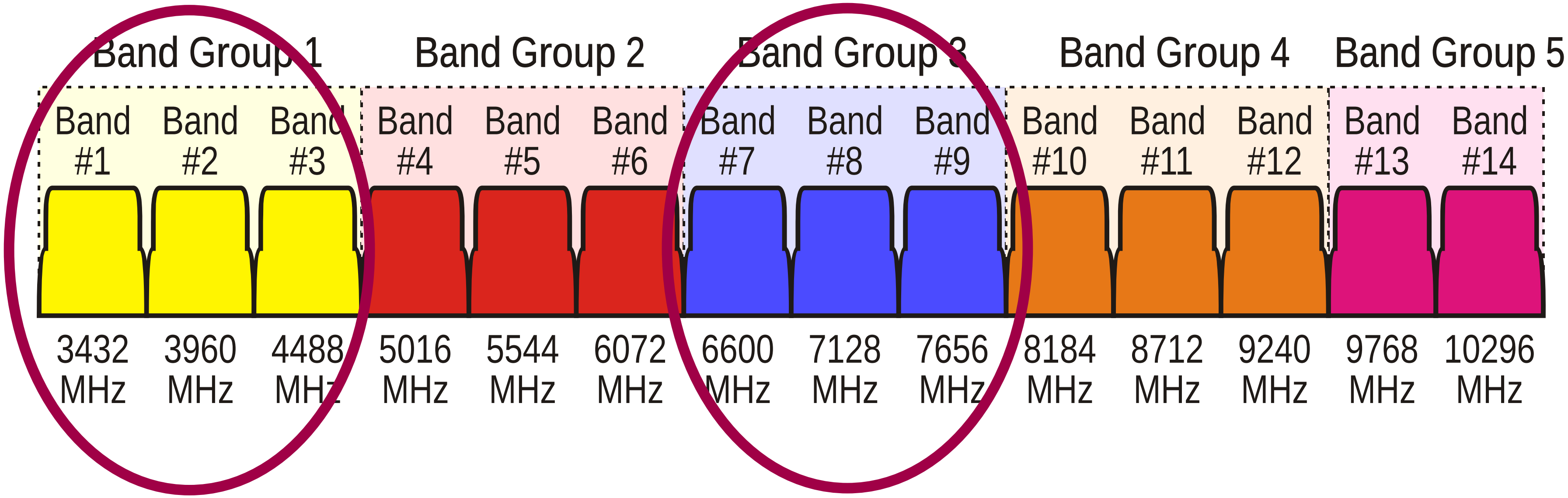
Shared members of WiMedia Alliance and Ecma submitted the WiMedia UWB platform specifications to Ecma in early 2005. Those specifications were drafted by Alliance members from the world's most prominent consumer electronics, mobile device, personal computer and semiconductor companies. Working in Ecma, experts aided in the final completion of the ECMA-368 standard: the physical (PHY) layer the Media Access Control (MAC) layer specifications. Separately, the ECMA-369 standard specifies the MAC-PHY interface.

"We are happy to see the rapid development of the UWB layers after such wireless systems have been studied for a long time," said Jan van den Beld, Secretary-General of Ecma. "Ecma expects that industry will now quickly take advantage of these standards by implementing various low-cost wireless

http://www.ecma-international.org/publications/standards/Ecma-368.htm

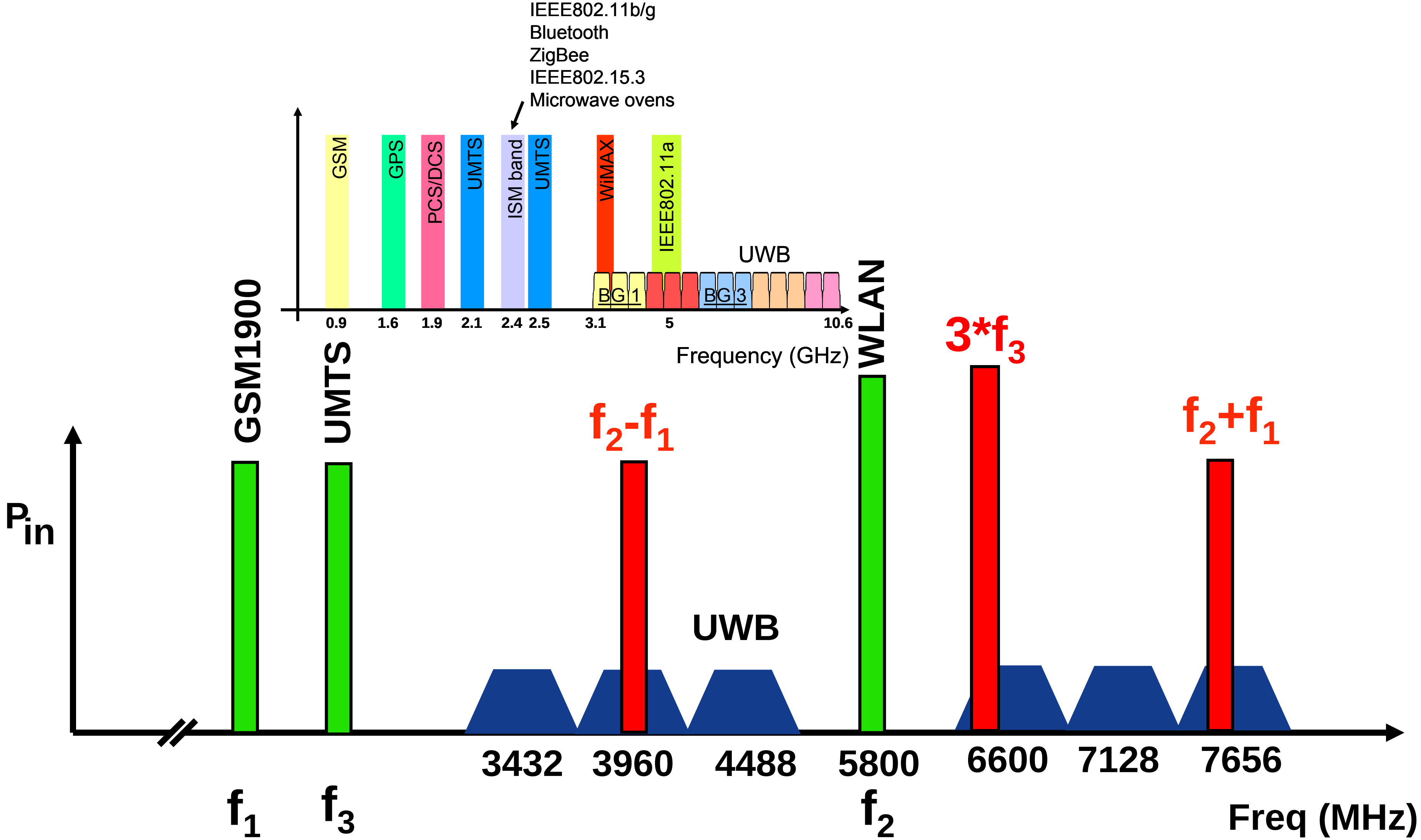
New challenge: dual band group operation

- New targets
  - Dual band operation with single signal path
  - Deal with change in interferer scenario
  - All-digital PLL based multi-tone generator (6 frequencies)

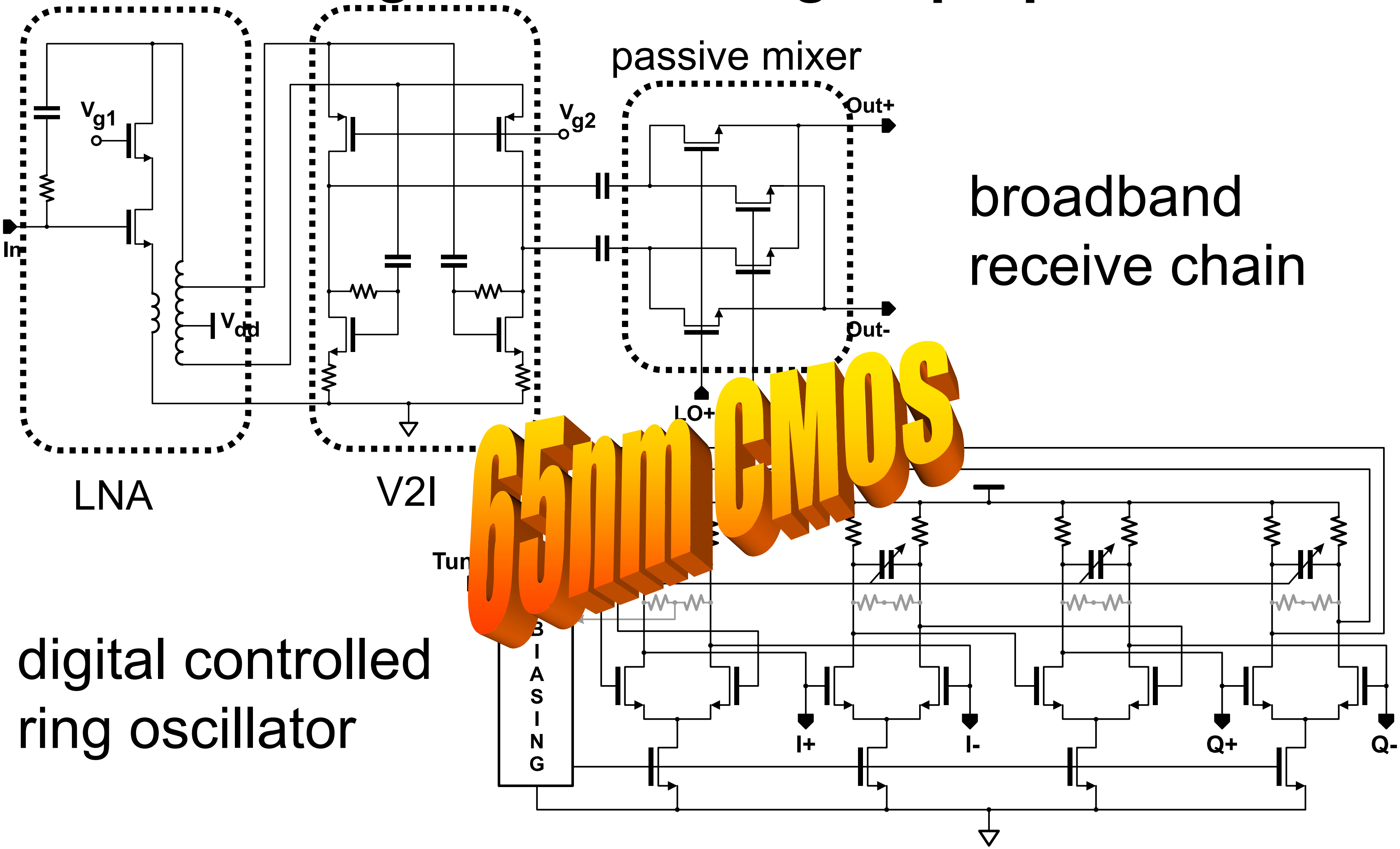


Coverage of Europe

New challenge: dual band group operation



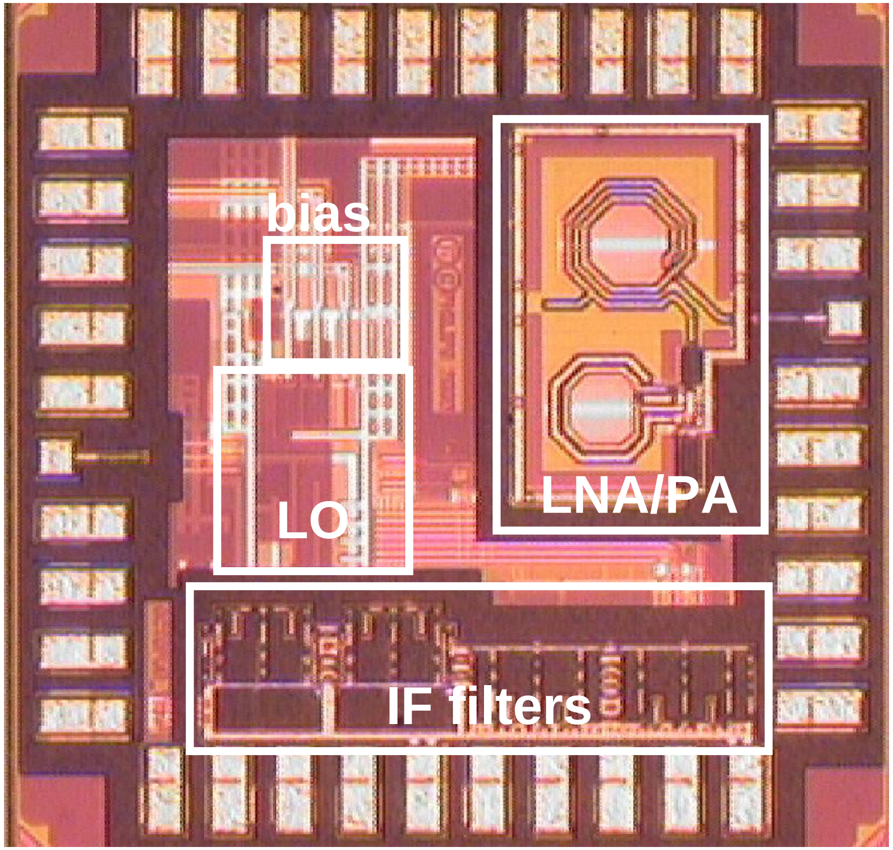
New challenge: dual band group operation



broadband receive chain

digital controlled ring oscillator

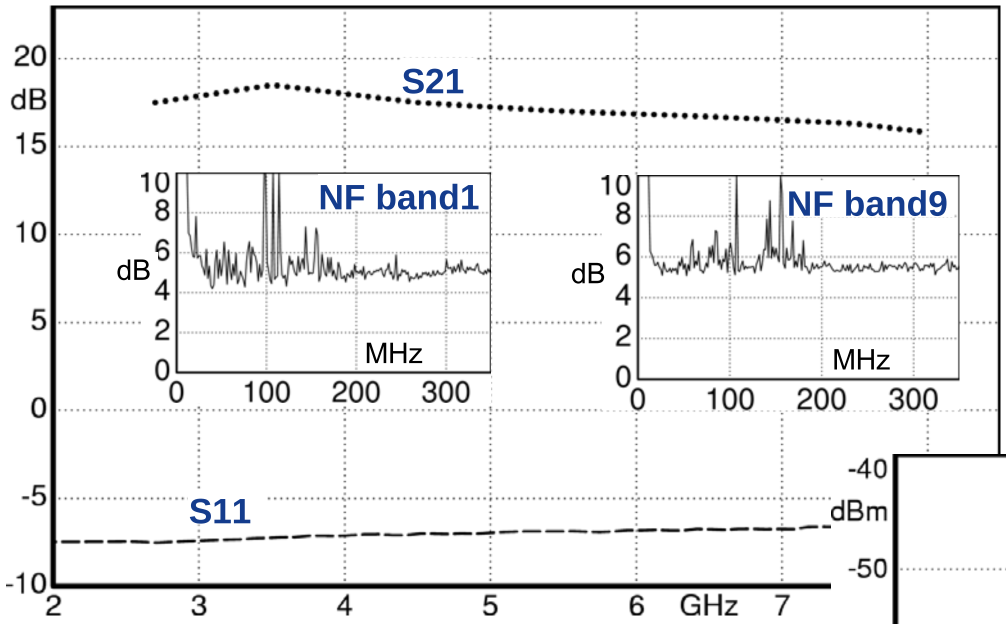
2006: dual band in 65nm CMOS

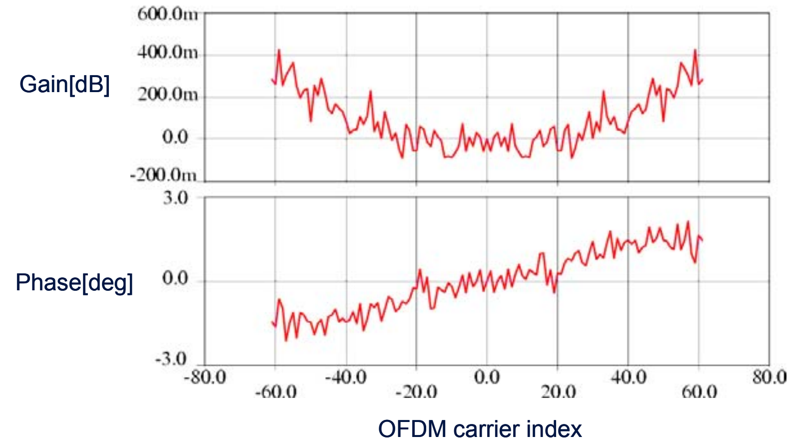


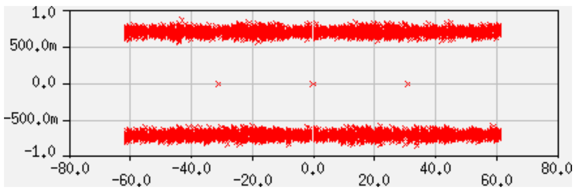
Parameter	Value	Comment
Rx noise figure	5.0 / 5.5 dB	f_{in}= 4 GHz / 7 GHz
Rx Gain	20 dB	Voltage gain, RF input to IF-output
Rx IIP2	+25 dBm	Two-tone: f_{in1}=2.4 GHz, f_{in2}=5.2 GHz
Rx IIP3	+6 dBm	Two-tone: f_{in1}=1.8 GHz, f_{in2}=2.4 GHz
Tx gain	+52 dB	IF-input to mixer output, w/o PA
Tx output EVM	4 %	At mixer output, w/o PA
Tx output flatness	< 2 dB	At mixer output, 3.2 -- 7.7 GHz
Dissipation @ 1.2V	52 mW 48 mW 63 mW	Receiver Transmitter LO generation

[ISSCC2007]

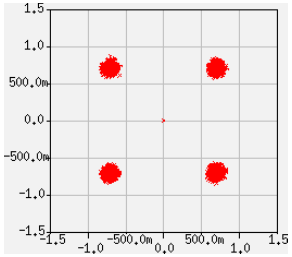
2006: dual band in 65nm CMOS

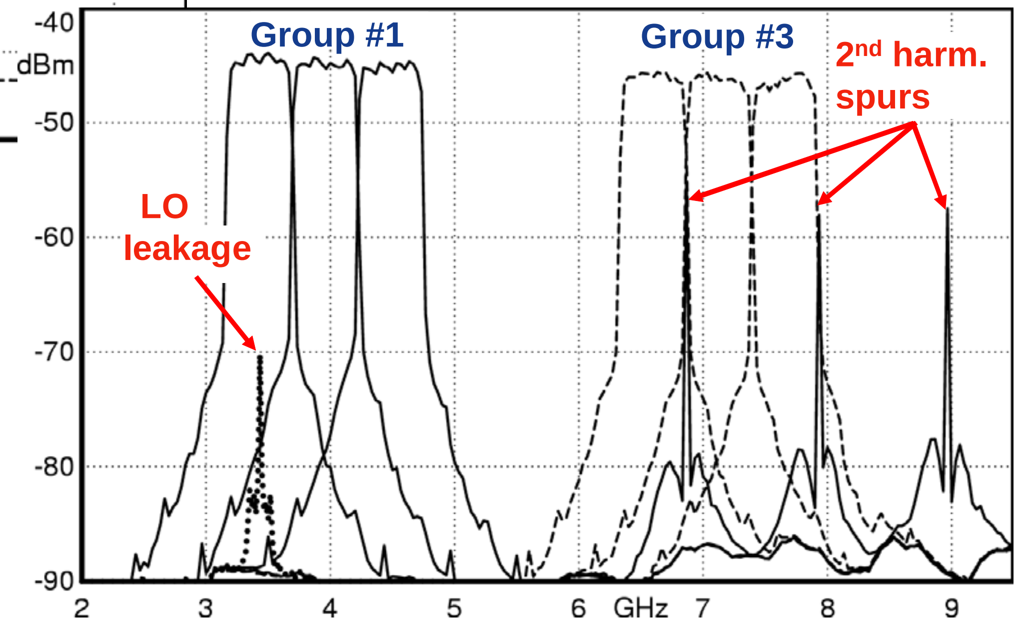






Equalized
EVM = 3.5 %





2006: dual band in 65nm CMOS

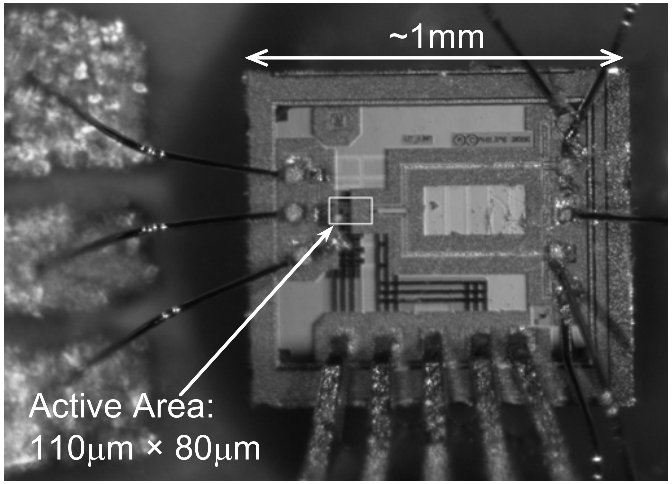
Parameter	This work	Ref [1]	Ref [2]	Ref [3]
Technology	65nm CMOS	130nm CMOS	130nm CMOS	90nm CMOS
Band Group	1, 3	1	1	1, 3, 4
NF (dB)	5	6-7	4.1	6.9
iIP3 / iIP2 (dBm)	+5 / +24	-15 / ?	-22 / ?	-16 / ?
TX EVM (dB)	-25 (-30)	-19.5	-27	-28
Pdiss Rx (mW) Pdiss Tx (mW)	114@1.2V 108@1.2V	100mA @ 3.3/1.5V 70mA @ 3.3/1.5V	237@1.5V 284@1.5V	224@1.1V 131@1.1V
Chip area (mm^2)	1	2	6.6	3.5

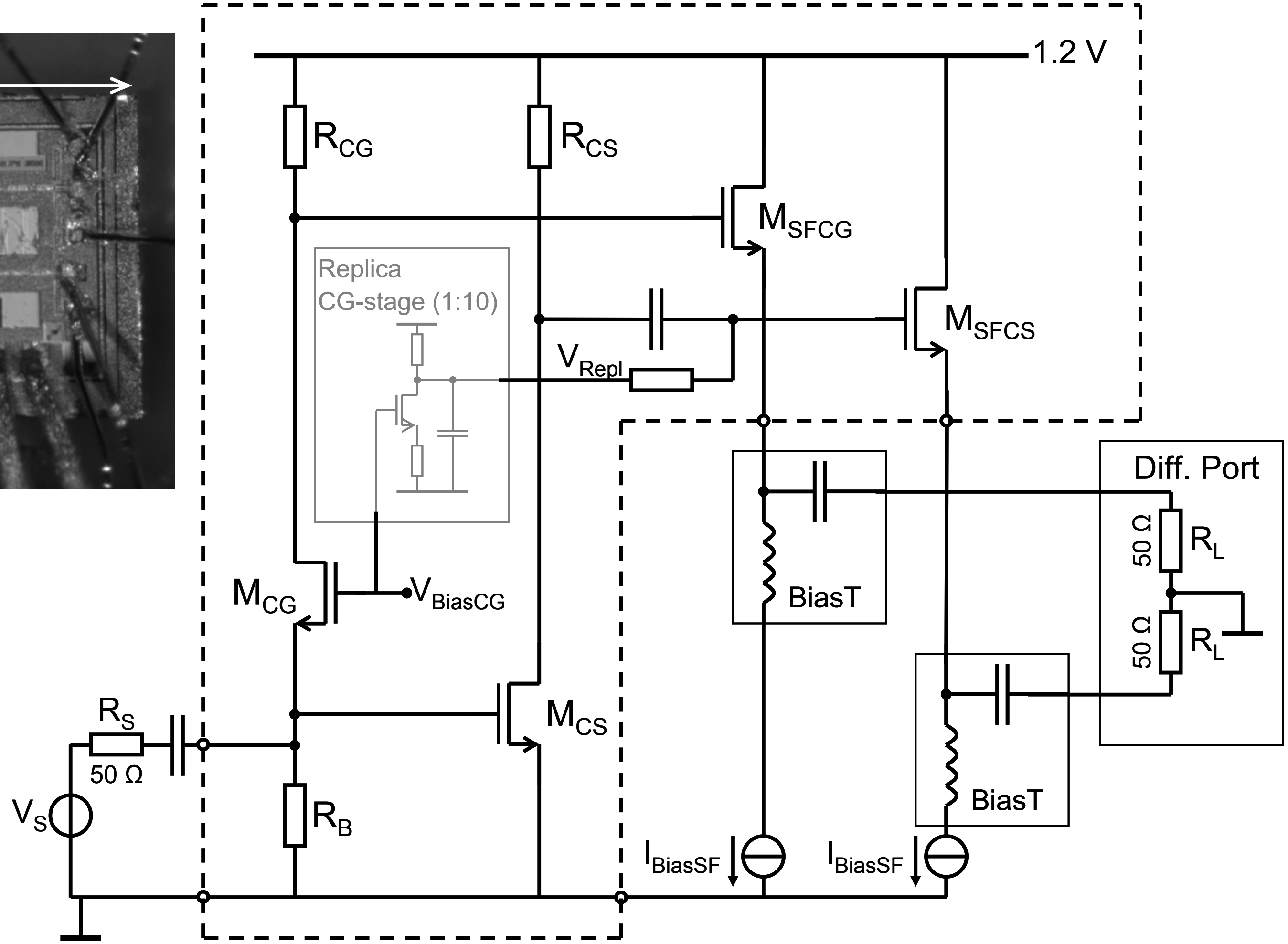
[1] T. Aytur et al., 2006

[2] C. Sandner et al., 2006

[3] A. Tanaka et al., 2006

‘our’ PhD demonstrated inductorless LNA





[Blaakmeer ESSCIRC07/ISSCC2008]

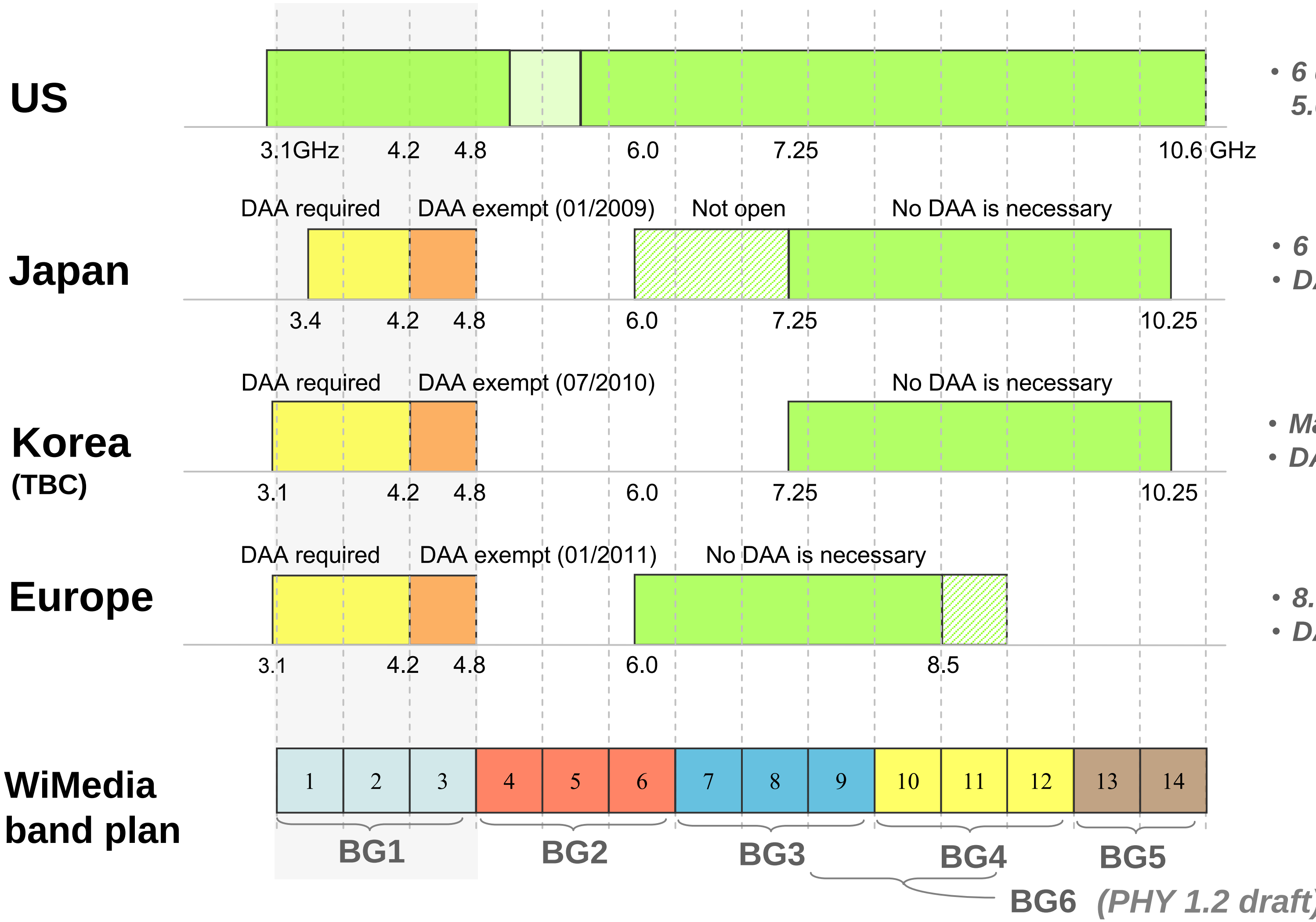
And what next.....?

- So far, we demonstrated that:
  - 65nm adequate for dual band group operation
  - Co-existence to allow co-operability systems is possible
- Others demonstrated that:
  - Inductorless broad band LNA is possible
- Therefore project OCTOPUS could be terminated (we thought)

2006: Cellular embraces w-USB

Triple band, DAA, co-existence and co-habitance

Cellular: world-wide operability



- *6 dB less power in 5.03 – 5.65 GHz*

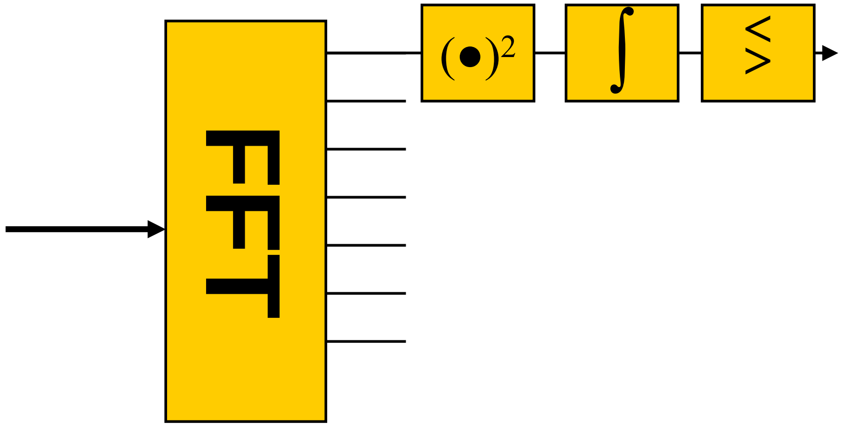
- *6 – 7.25 may open*
- *DAA TBD*

- *Mask, OOB TBD*
- *DAA TBD*

- *8.5 – 9 may open*
- *DAA TBD*

Cellular: world-wide operability

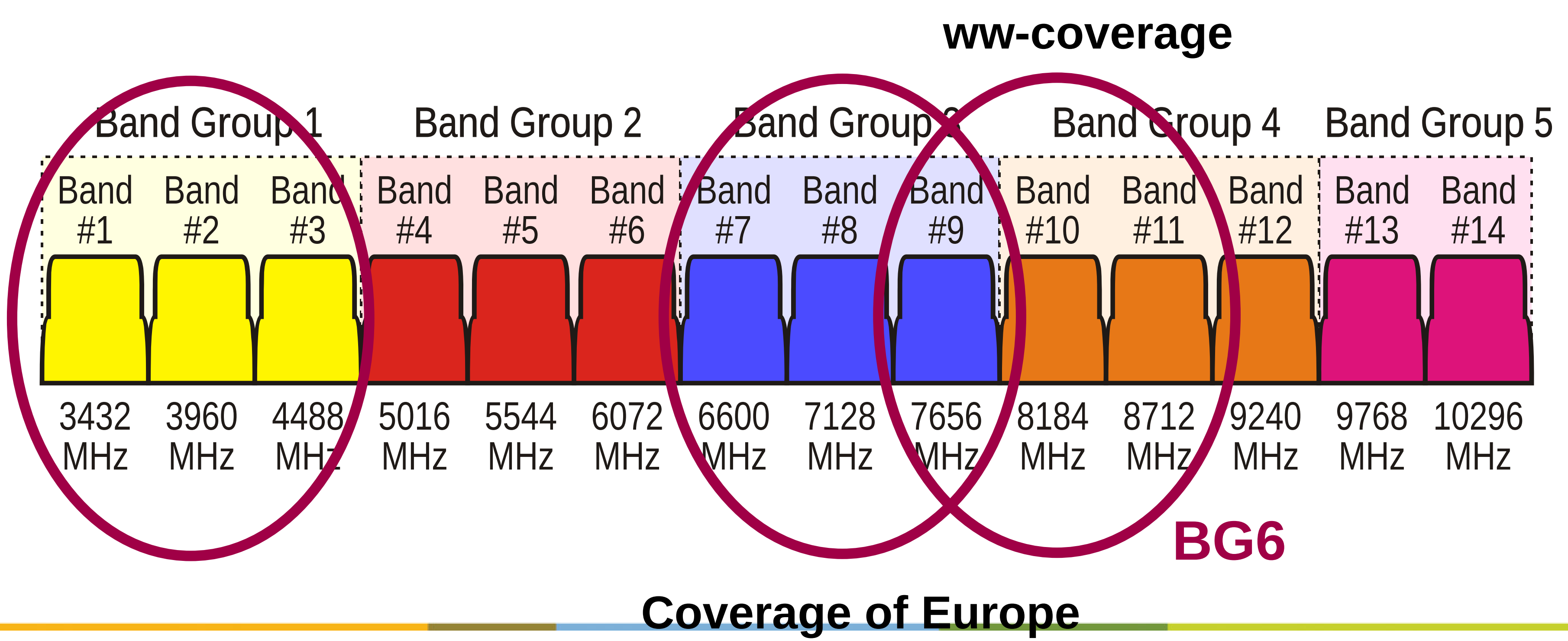
- Detect (e.g. WiMAX) and Avoid (DAA)
  - Detect using channelized radiometer



  - Avoid using 5 nulling tones as replacement for OFDM data tone #24 - #28
    - Requires linear TX and higher DR of DAC
  - Avoid using skipping sub-band
    - Lower transmit power

New challenge: triple band group operation

- New targets
  - Triple band operation with single signal path
  - Deal with co-habitance
  - Deal with DAA



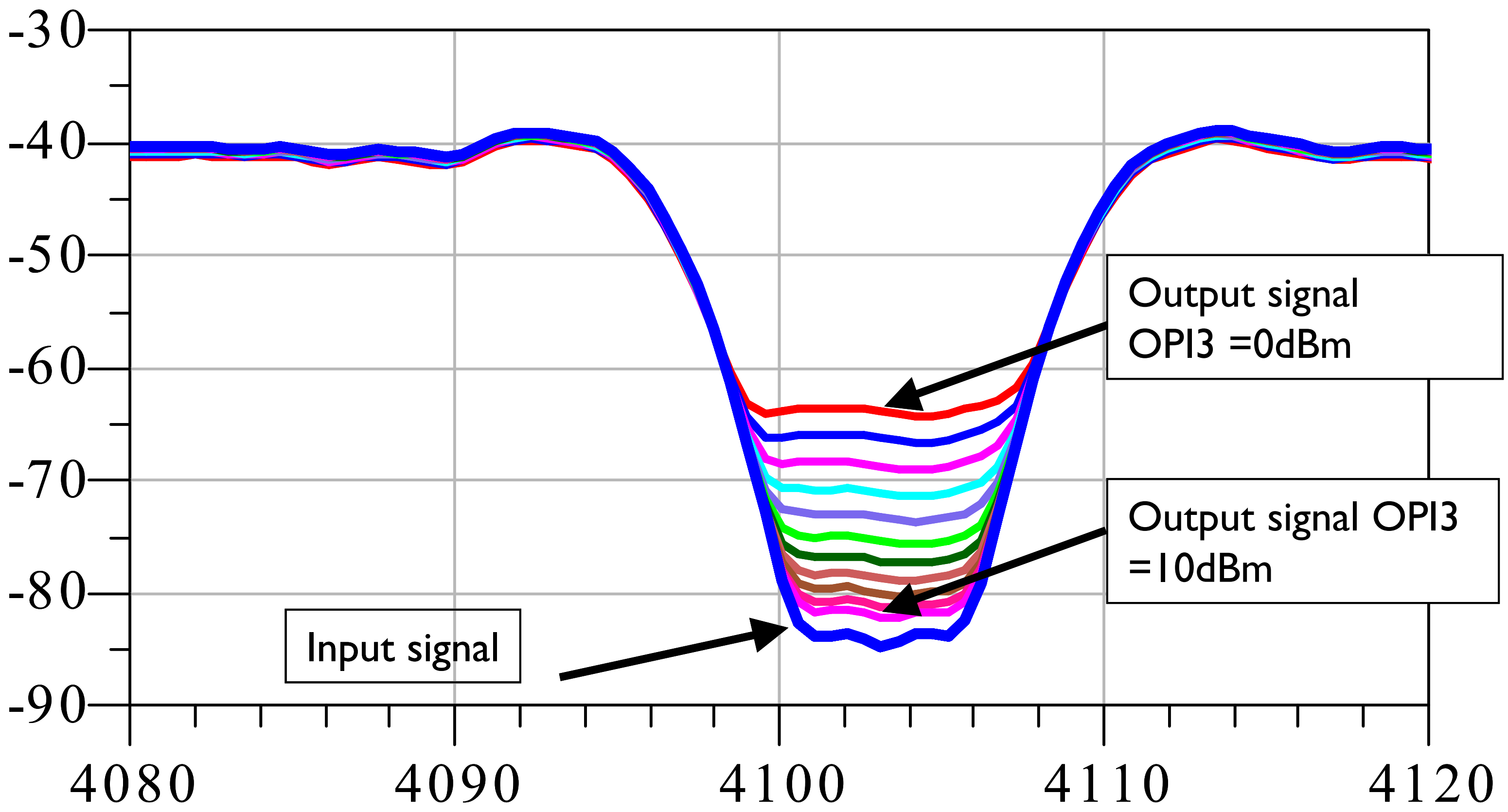
Challenge of cellular co-existence

- Previous scenario: laptop environment
  - 20cm distance between UWB and WLAN antenna's
  - At least 1m distance between UWB and cellular antenna

- Cellular environment
  - 5cm distance between UWB and cellular antenna, share same PCB!
  - Only 15dB attenuation due to 'air-link'
  - Additional attenuation by pre-filter
  - But, e.g. GSM, WiMAX have +30dBm transmit powers
  - Extreme requirements for linearity and on-chip filtering at RF/BB

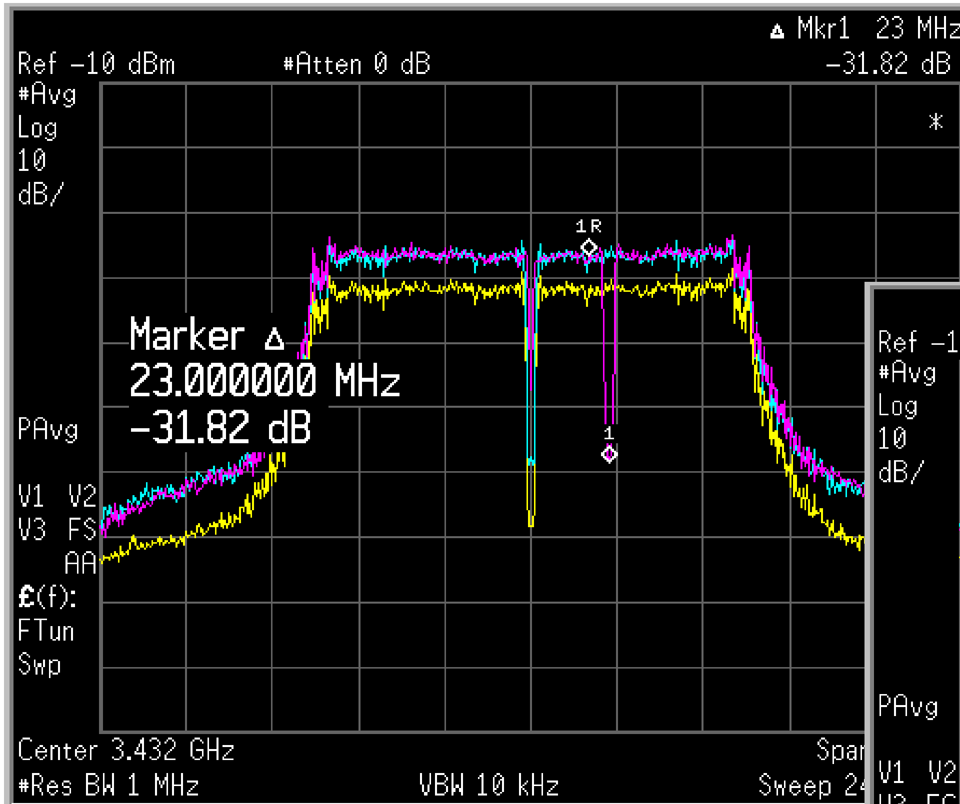
- Extreme co-habitance
  - Bluetooth radio on the DBB/MAC

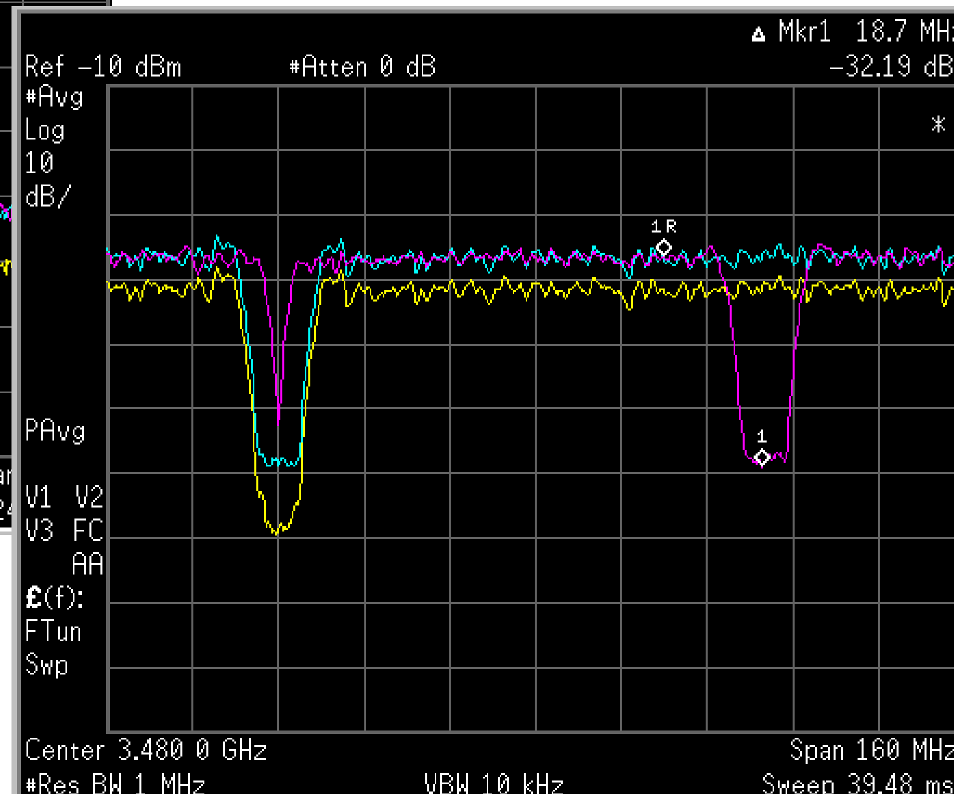
Challenge of DAA



44dB notch is reduced by at least 3dB due to OIP3 of TX

Challenge of DAA





Measured notch for DAA using AIC algorithm [Yamaguchi, 2004]

Depth depends on TX linearity, LO leakage, etc

What about newer CMOS technologies?

- As we are researchers, just for the fun:

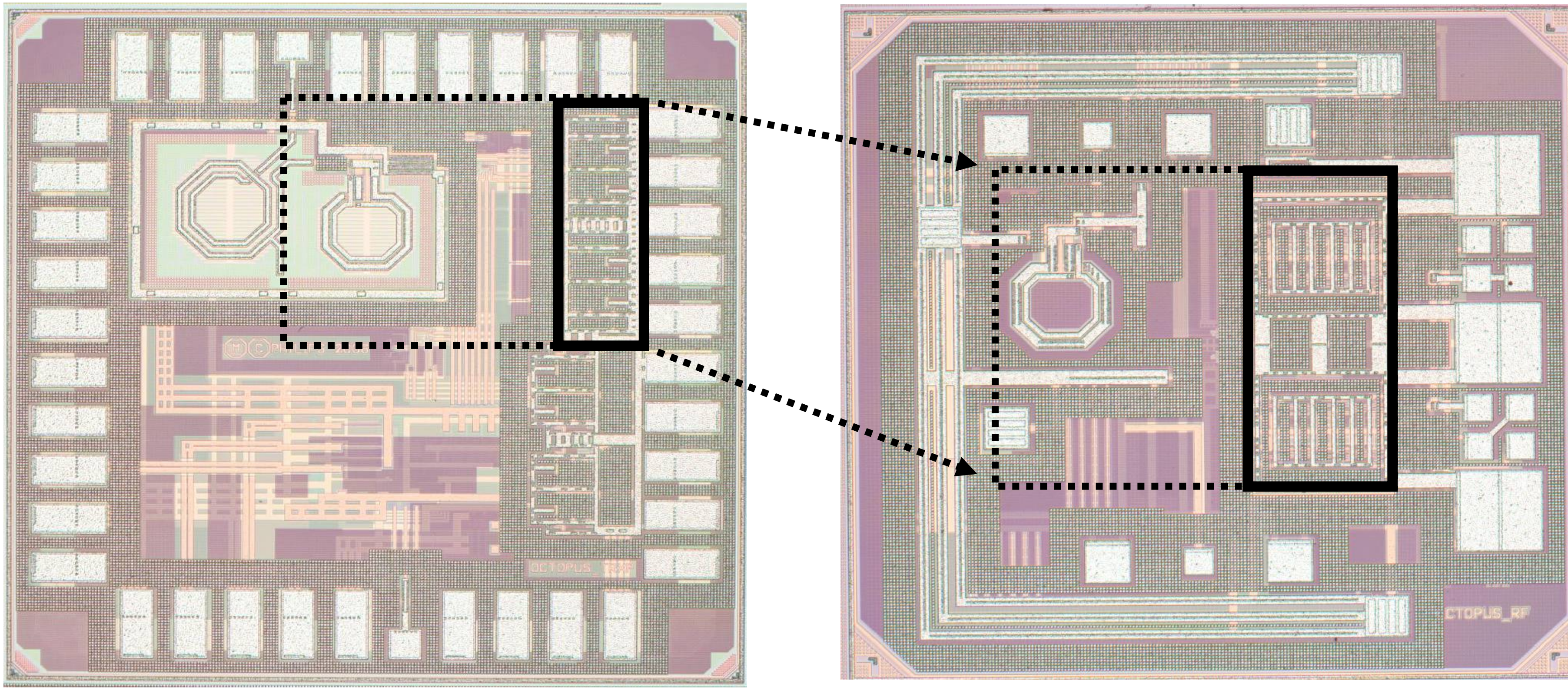
migrate 65nm dual-band UWB receiver to 45nm

  - Taped out October 2006

- Approach
  - Take chosen 65nm architecture 'as is'
  - Modify MOS sizes where appropriate
  - No optimization for area

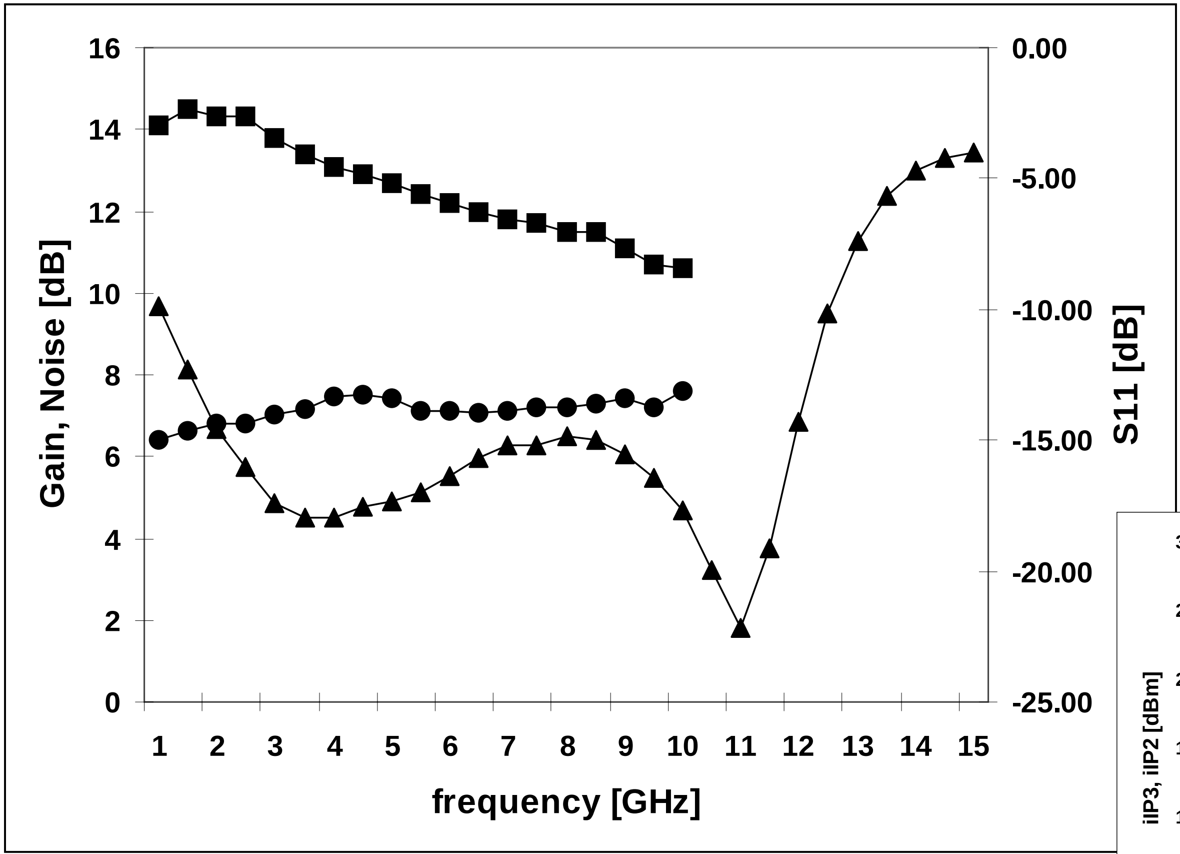
What about newer CMOS technologies?

65nm LP CMOS **45nm LP CMOS**



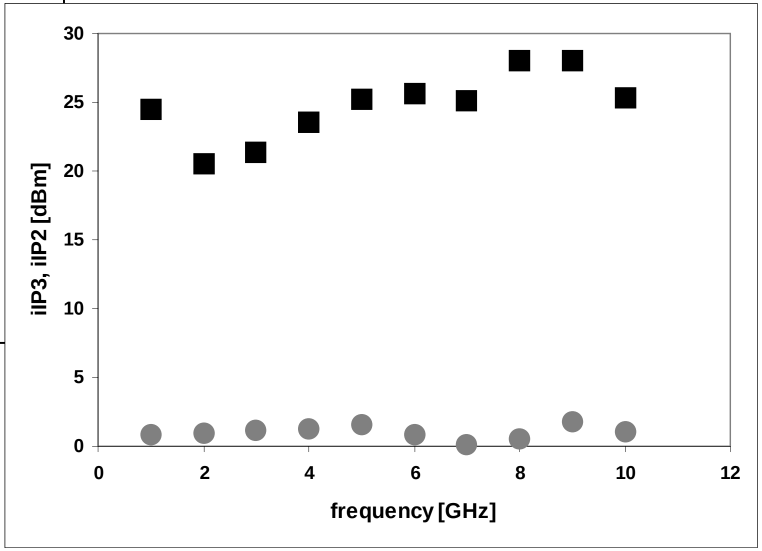
45nm BB-TIA consumes twice the area

What about newer CMOS technologies?



Measured voltage gain (squares), noise figure (dots), and s11 (triangles)

Measured IIP2 (squares) and IIP3 (dots)



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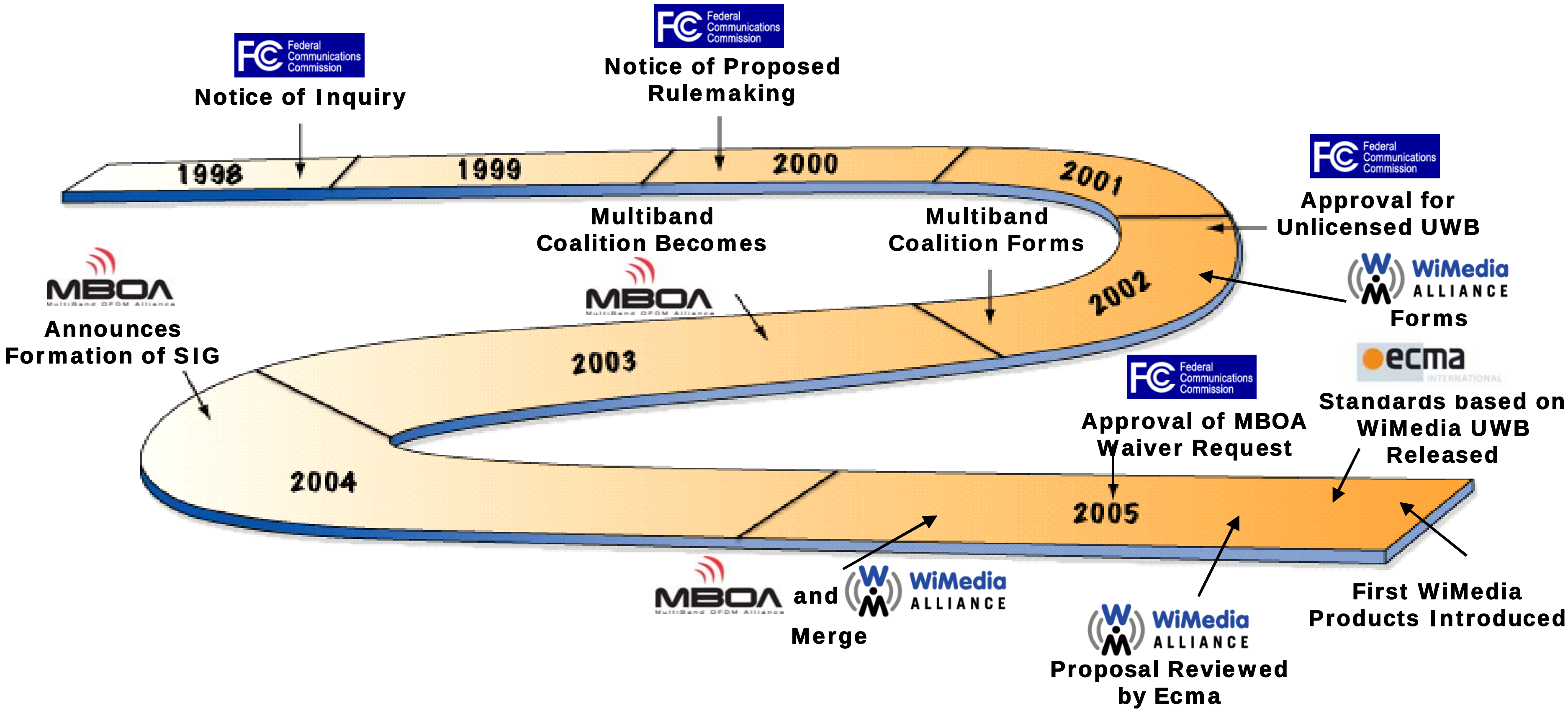
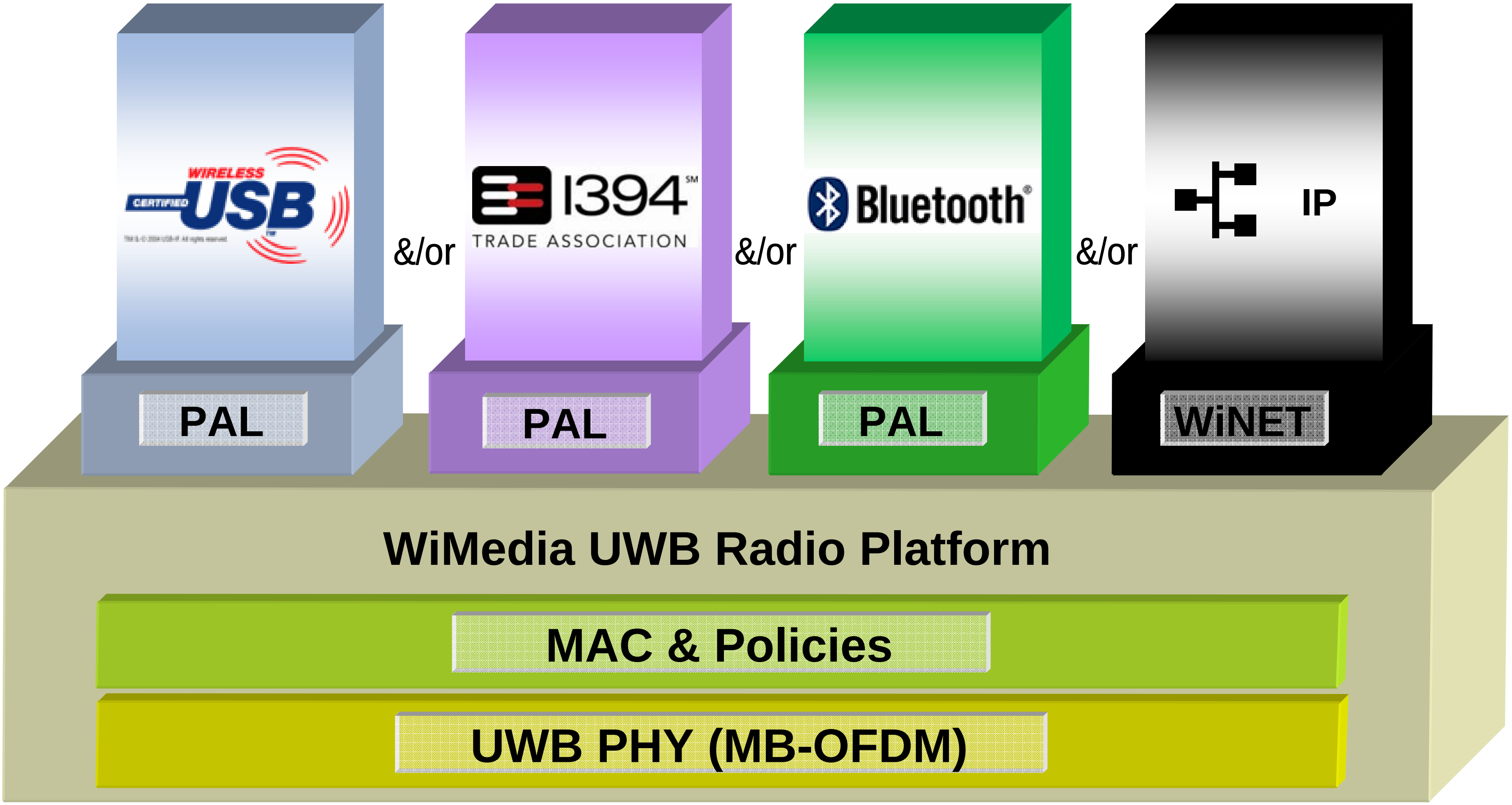
Concluding remarks

It was a long road, …



2008: products enter the market

but the future is bright



PAL: Protocol Adaptation Layer

Acknowledgements

- The OCTOPUS 'Research' team, base din Eindhoven, the Netherlands
- Members of the BL connectivity, based in San Jose