Analog and RF Requirements for Advanced CMOS Nodes: The SOI Perspective

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Outline

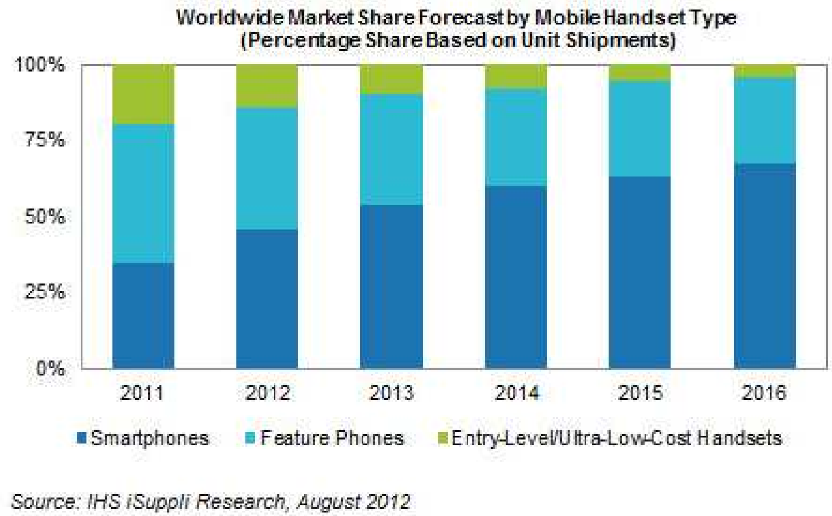
- **Wireless Business Overview: where are we heading to ?**
- **Tablets and Smartphones Build Of Manufacturing**
- **Is SOI CMOS Technology a good alternative for today challenges ?**
  - **Application Processor Performances Booster**
  - **Digital Baseband Performances/Consumption Tradeoff Improvement**
  - **RF transceiver performances improvement**
  - **Connectivity Combo Chip integration improvement**
  - **Front End Module Integration on Silicon**
- **4G System Architectures Trend: new challenges to come**
- **Can SOI CMOS Technology address future RF challenges ?**
- **Conclusion and Perspectives**

Wireless Business Overview

- ***Mobile phone*** market is quickly ***moving to smartphones***, in ***2Q12*** smartphones represent ***38% of the market*** (~153.9 millions units) in comparison with 25% in 2Q11 representing an ***increase of 42%*** year-over-year.

Apple iPhone 5

Samsung Galaxy S3



- ***Apple*** continues its inroad in the mobile market (***~26 millions iPhone*** units in ***2Q12***, **up** by ***27%*** in comparison with 2Q11) targeting the ***premium customers*** (capturing ***73%*** of ***1Q12 handset profits*** with a ***market share*** of only ***9%*** of the global handset market).

- ***Apple*** and ***Samsung*** now ***dominate the smartphone market*** with ***combined market share*** of nearly ***50%***.

Wireless Business Overview

- ***Google*** is the one who delivered a competitive solution to Apple with the ***Android OS*** and its ***OEM community*** (HTC, Huawei, LG, Motorola, Samsung, Sony Ericsson, ZTE).

Top Six Smartphone Operating Systems, Shipments, and Market Share, 2012 Q1 (Units in Millions)

Mobile Operating System	1Q12 Unit Shipments	1Q12 Market Share	1Q11 Unit Shipments	1Q11 Market Share	Year-over-Year Change
Android	89.9	59.0%	36.7	36.1%	145.0%
iOS	35.1	23.0%	18.6	18.3%	88.7%
Symbian	10.4	6.8%	26.4	26.0%	-60.6%
BlackBerry OS	9.7	6.4%	13.8	13.6%	-29.7%
Linux	3.5	2.3%	3.2	3.1%	9.4%
Windows Phone 7/Windows Mobile	3.3	2.2%	2.6	2.6%	26.9%
Other	0.4	0.3%	0.3	0.3%	33.3%
Total	152.3	100.0%	101.6	100.0%	49.9%

Source: IDC Worldwide Mobile Phone Tracker, May 24, 2012

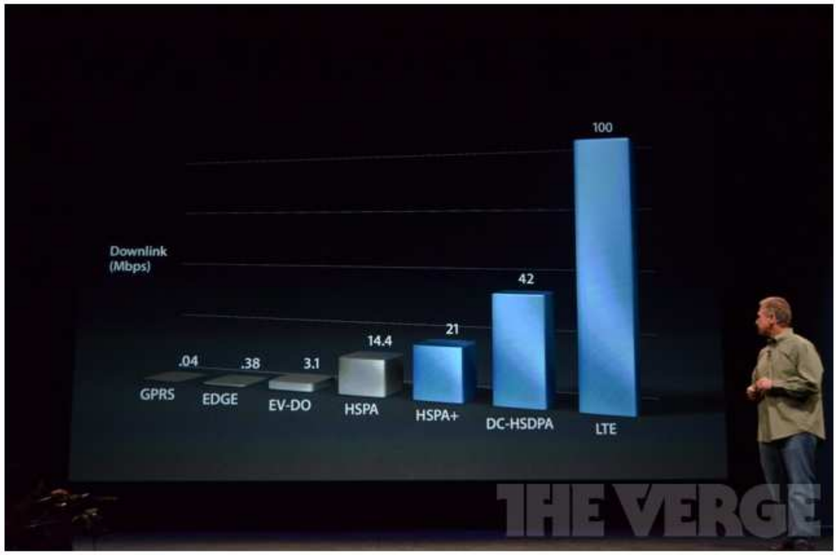
- ***Android*** became the ***leading smartphone platform*** in ***4Q10*** and in ***2Q12*** Android based smartphones represent ***59%*** of the smartphone market (***up 145%*** year-over-year).

- ***Emerging markets*** (China, India, and Brazil) represent now the ***strongest market opportunities*** for smartphone makers. So ***chipset cost matters,*** we can already see a fierce competition on the Chinese market (with ***MediaTek*** to ship ***95 millions*** of its low cost ***MT6575/6577*** solutions ***in 2012*** and ***expected*** to reach ***200 millions*** parts in ***2013***).

Wireless Business Overview

- Coming back to hardware, ***LTE*** capability is currently the ***next hot feature*** everybody is looking at. The ***US*** market is ***leading*** the ***LTE deployment*** with carriers in Japan and South Korea investing heavily in 4G LTE technology deployments.

Apple iPhone 5



- ***4G devices*** are ***redefining smartphone formats***, moving to ***larger touch screens*** (4.5" or 5") while ***pushing the thickness*** of the device ***to new*** record ***low*** (< 8 mm).

- Moreover, as we will discuss later, moving to ***4G will bring us to deal with a lot of new challenges*** since we will have to ***support numerous new frequency bands***.

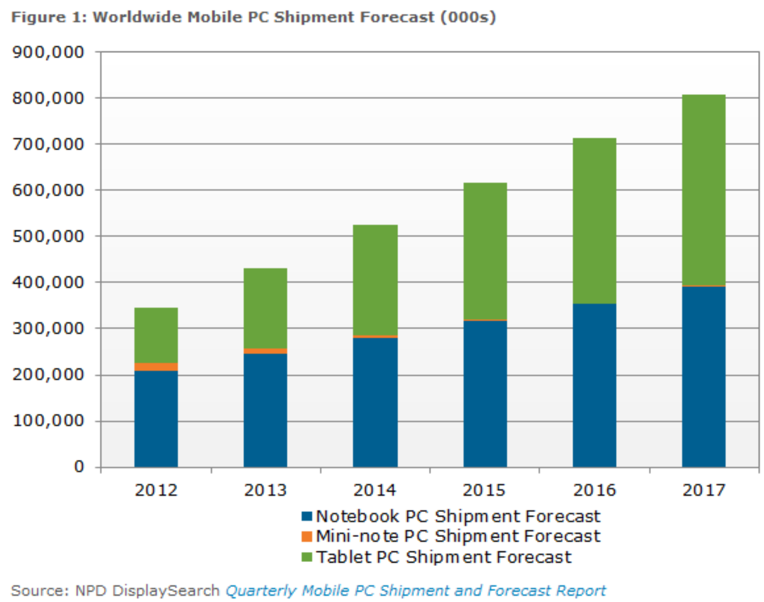
Wireless Business Overview

- ***But*** smartphone is not the only force in action here, ***tablet is also playing a key role*** with ***24.994 Millions*** tablet shipped in ***2Q12*** (up ***66.2%*** year-over-year).

Apple iPad

Samsung Galaxy Tab 10.1

Amazon Kindle Fire



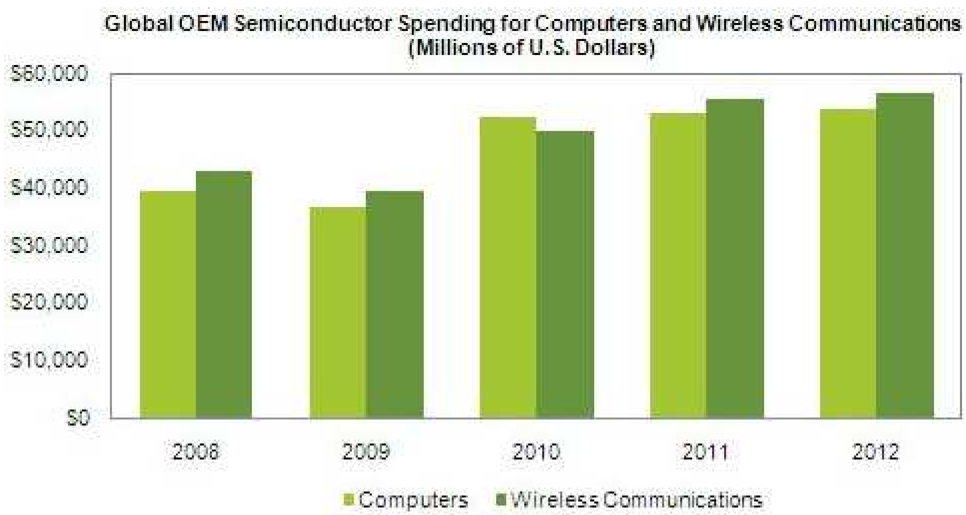
- Apple and the ***iPad*** (***17.042 millions units*** in ***2Q12***, ***up 84.2%*** over 2Q11) are currently holding ***61.5% market share*** in ***2Q12*** (in comparison with ***75% in 2011***) while ***Android tablet*** now holds ***38.5% of the market*** mainly thanks to Samsung and Amazon.

- It is interesting to note that the ***rise of the tablet market*** is coming ***at the expense of the netbook*** one and in the ***future*** it is believed that ***tablet could*** even ***supplant laptop***.

Wireless Business Overview

- So, ***wireless business*** is ***fueling*** the ***semiconductor industry*** with the rapid expansion of ***smartphones*** and ***tablets***.

- According to researches, original equipment manufacturers (***OEMs***) have ***spent more on semiconductors for wireless devices than computers in 2011*** ($55.4 billions on semiconductors for phones and tablets in 2011, as compared to $53.1 billions on PC silicon)

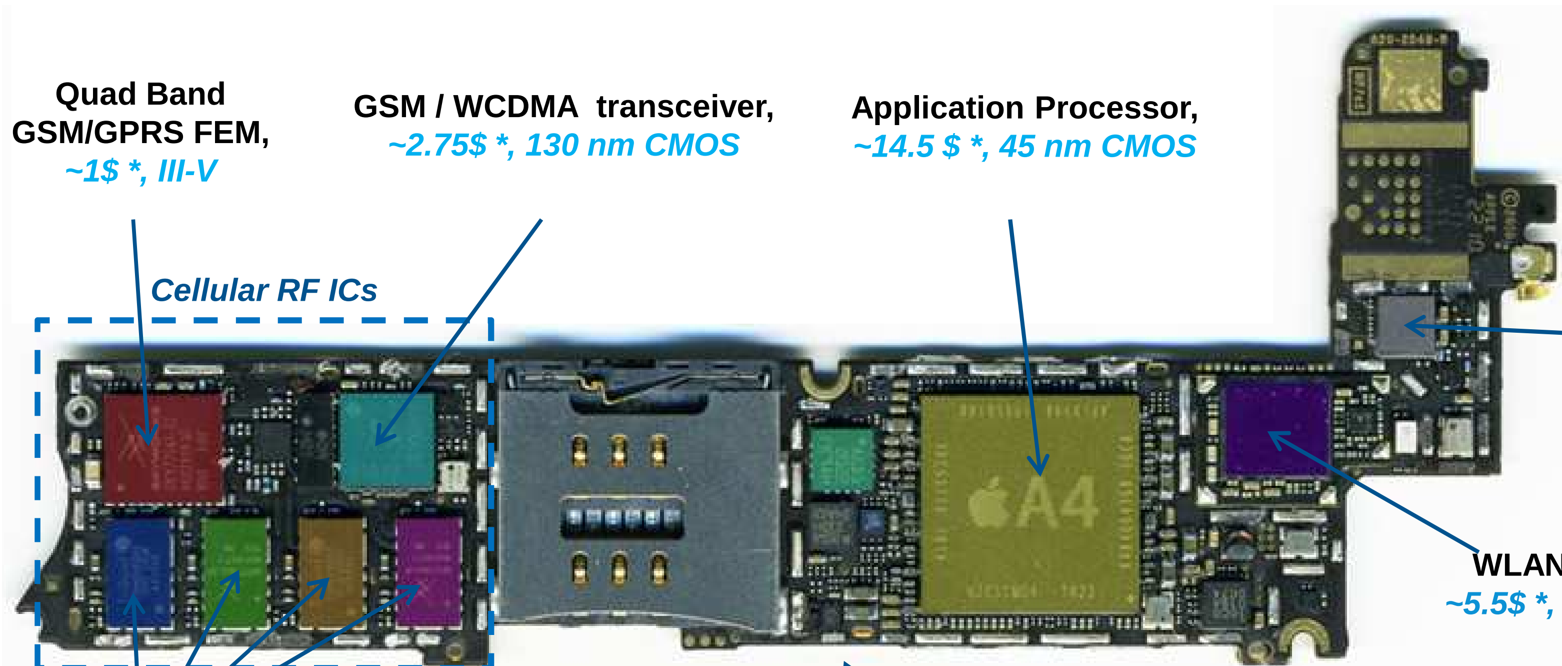


Source: IHS iSuppli August 2011

- So the ***key question*** is now if ***SOI CMOS technology*** can play a role here in order to ***bring product differentiation*** or ***address challenges faced by the wireless industry***.

Smartphones BOM

Apple iPhone 4 Teardown:

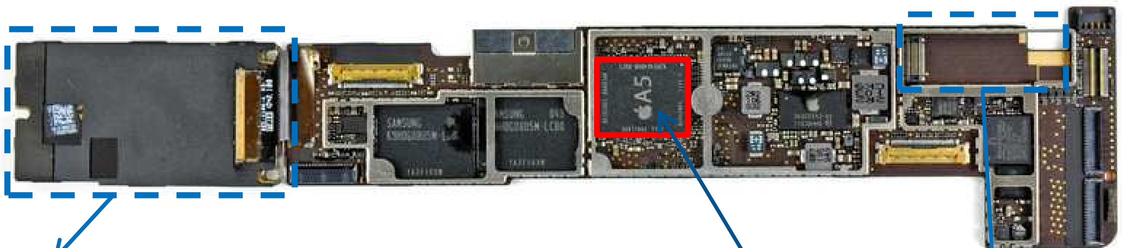


Board photo from http://www.ubmtechinsights.com/

*: estimation, may change according to situation

Tablets BOM

Apple iPad 2 3G Teardown:



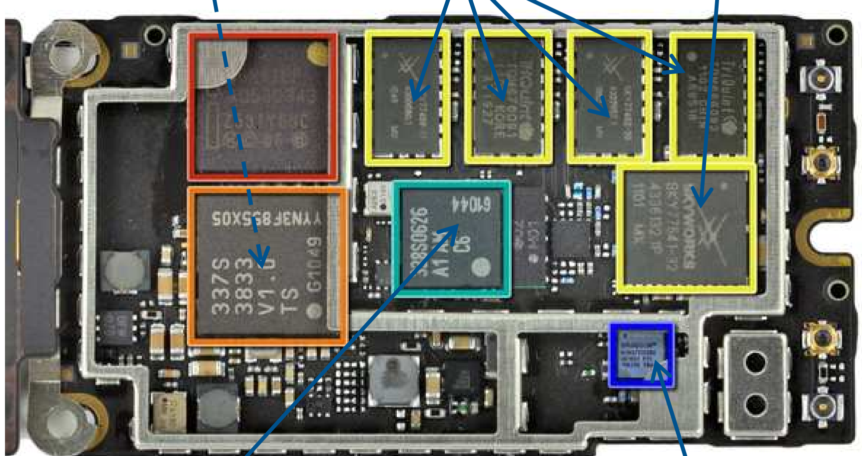
Application Processor,
*~14.5 $ *, 45 nm CMOS*

Cellular RF ICs Board

Baseband Processor,
*~11.5$ *, 65 nm CMOS*

WCDMA PAs,
~1.25$ per module, III-V*

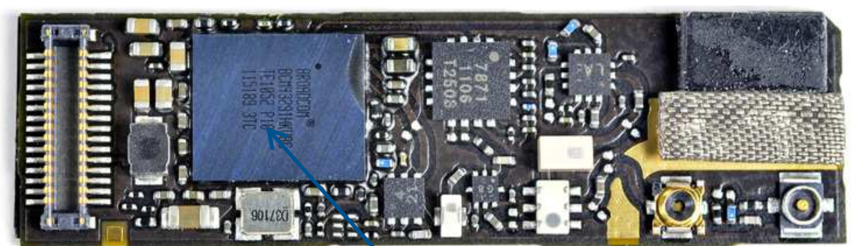
Quad Band GSM/GPRS FEM,
*~1$ *, III-V*



GSM / WCDMA transceiver,
*~2.75$ *, 130 nm CMOS*

GPS, *~2.5$ *, 90 nm CMOS*

WiFi Board



WLAN/Bluetooth,
*~5.5$ *, 65 nm CMOS*

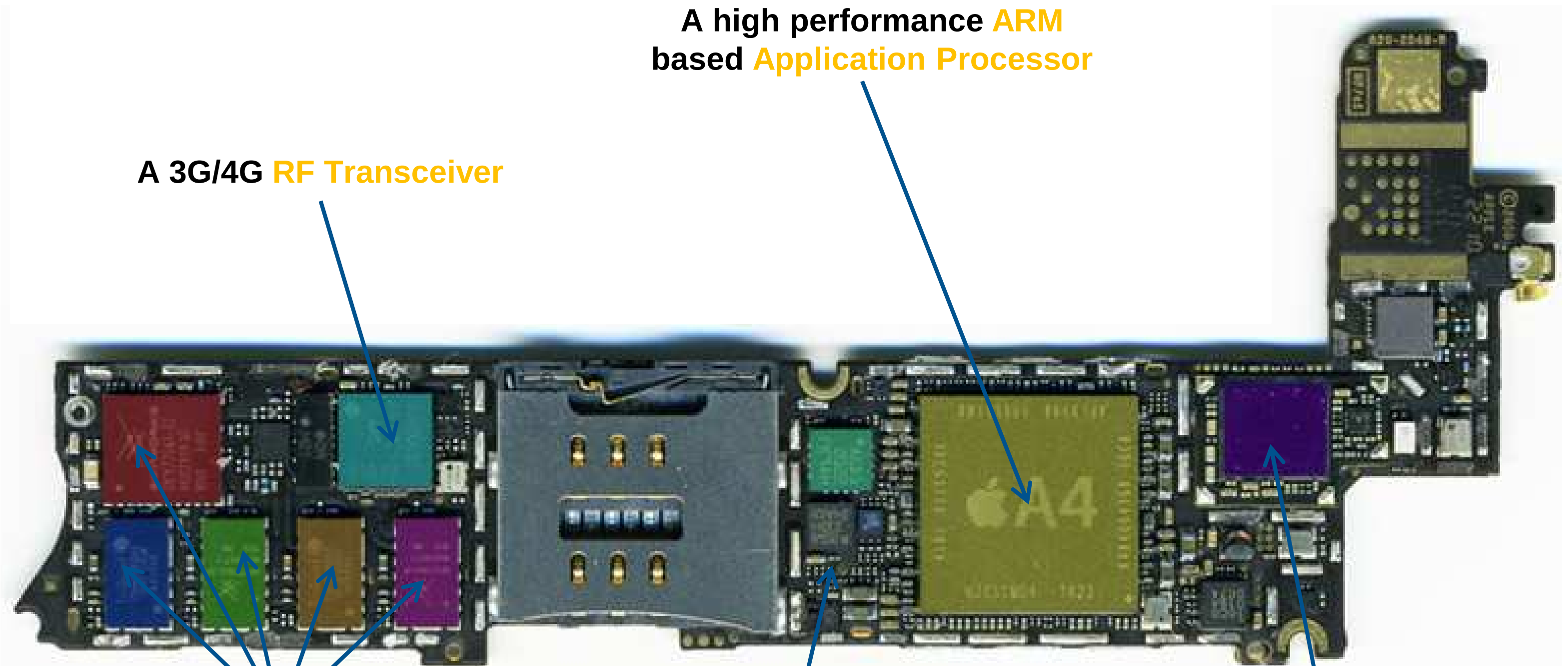
Board photo from http://www.ifixit.com/

Tablets and Smartphones BOM

- In the end, ***smartphones*** and ***tablets*** wireless IC ***BOM*** are ***almost the same*** … Then, we can summarize tablets and smartphones wireless IC requirement as follow:

A high performance ARM based Application Processor

A 3G/4G RF Transceiver



Front End Module ICs

A high Speed (LTE) Baseband Processor (Modem)

A low cost combo connectivity Chip (WiFi/Bluetooth/FM Radio)

- The ***key question*** is now to know if ***SOI CMOS technology*** can help in order to ***address the current challenge faced by those 5 kinds of ICs*** ?

Is CMOS SOI a Good Alternative ?

- We can ***summarize*** the ***requirements of wireless business*** for ***advanced CMOS technology*** as follow:

  - High performances ***application processor:***
    Ensure ***high speed*** operation under ***low power consumption*** constraints

  - High speed ***baseband processor:***
    Help to ***improve*** the ***cost/performance/power consumption tradeoff***

  - 3G/LTE ***RF Transceiver:***
    Help to ***reduce*** the ***power consumption*** and ***improve*** the ***RF performances***

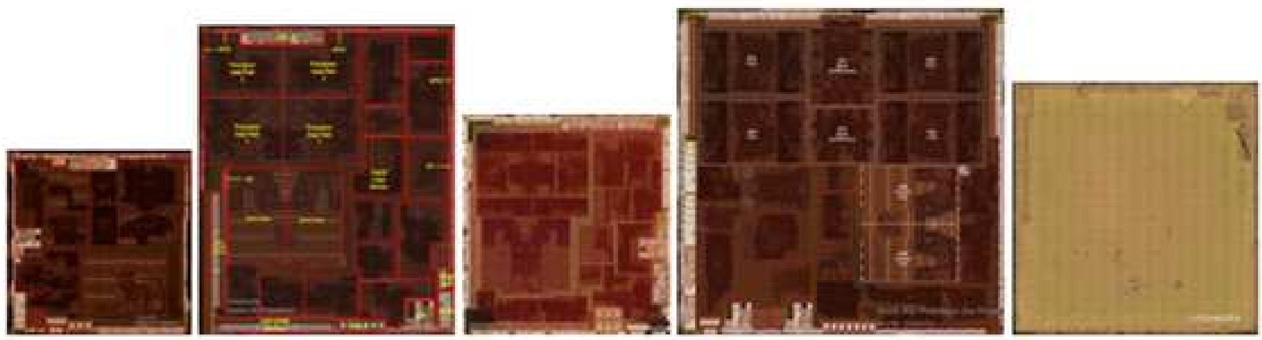
  - Combo ***connectivity chip:***
    Enable the ***integration*** of remaining ***off chip features***

  - ***Front End Modules:***
    Enable the ***integration*** of FEM ***on silicon*** in order to improve both integration and cost

- The good question now is to know if ***SOI*** can help to ***address*** any of ***those requirements*** in a more time and cost effective manner than traditional bulk CMOS technologies ***?***

Application Processor Challenges

- Clearly, ***application processor*** business is ***driven by performances*** in order to make ARM CPU the dominant processor platform leveraging mobile application trend.



In order from left to right:

A4	A5	A5 Gen 2	A5X	A6
45 nm	45 nm	32 nm	45 nm	32 nm
7.3 mm x 7.3 mm	10.09 mm x 12.15 mm	8.19 mm x 8.68 mm	12.9 mm x 12.8 mm	9.70 mm x 9.97 mm

http://www.presence-pc.com/actualite/iPhone5-A6-performances-48851/#xtor=RSS-11

- Main players are currently delivering ***1.5 GHz dual core Cortex A9 ARM processor***, aggressively ***moving to quad core Cortex A9*** and to ***dual Cortex A15***.

- In this quest, ***access to most advanced CMOS node (28 nm and below)*** has been so far the way to go.

Baseband Processor Challenges

- Moving from ***HSPA+*** (***12 Mbps***) to ***4G/LTE*** (***100 Mbps***), the design of advanced baseband processor becomes more and more challenging.

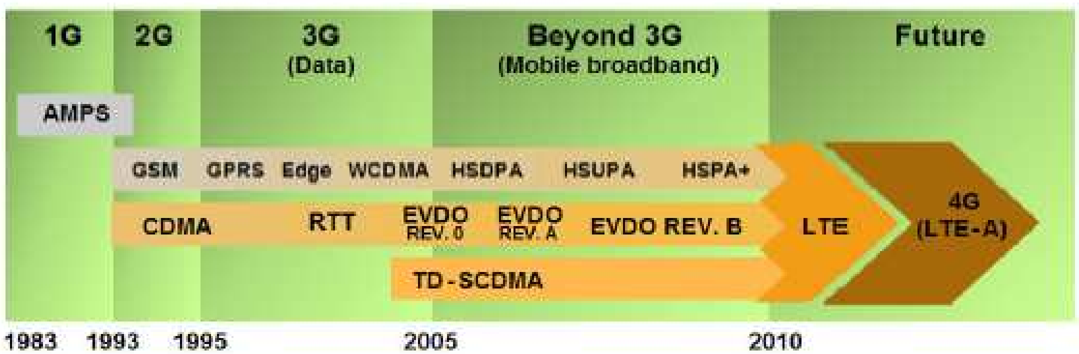


Figure 1: Cellular standards evolution from 1983 to present

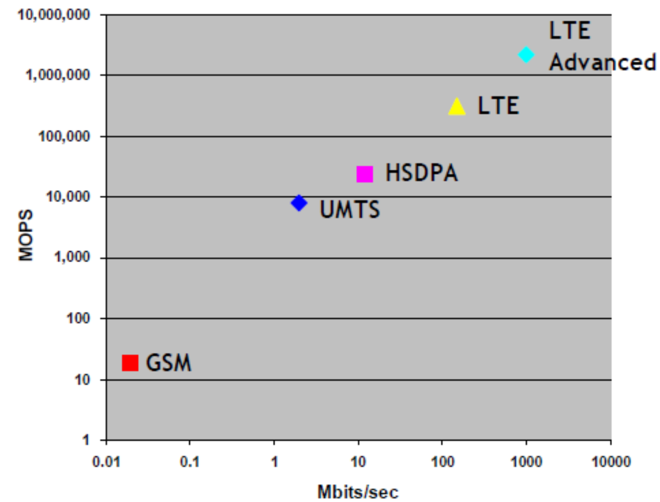


Figure 4: Cellular Radio Computation Levels (MOPS) versus Download Data Rates (Mbits/sec)

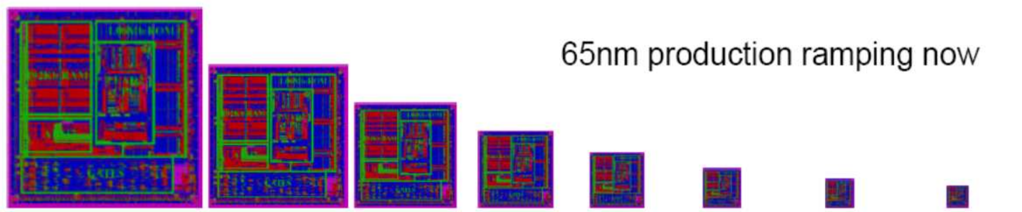
Source: " The Five Pitfalls of 4G Baseband SOC Design", Tensilca White paper,January 19, 2010

- ***Baseband processor*** manufacturers have now to deliver ***cost effective*** and ***power efficient DSP*** capable of ***delivering 100 000s MOPS*** (millions of operation per second).

Baseband Processor Challenges

- ***Up to now*** the use of most ***advanced CMOS node*** has been ***the answer***.

GSM Digital Baseband Evolution



Year	1994	1997	1999	2000	2002	2004	2006	2008
Nanometer	500nm	350nm	250nm	180nm	130nm	90nm	65nm	45nm
Wafer size	6"	8"	8"	8"	12"	12"	12"	12"
Die size (mm^2)	80.7	46.6	19.2	10.7	6.7	4.2	2.4	1.4
Dies per wafer	310	950	2550	4700	12,200	18,700	26,500	46,500

15000 % increase in dpw

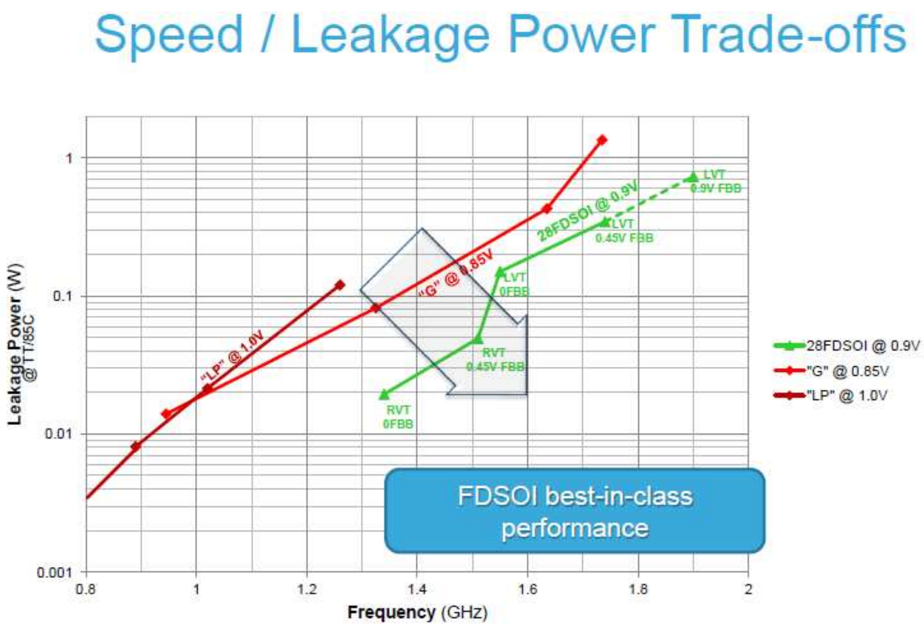
Technology for Innovators™ Texas Instruments

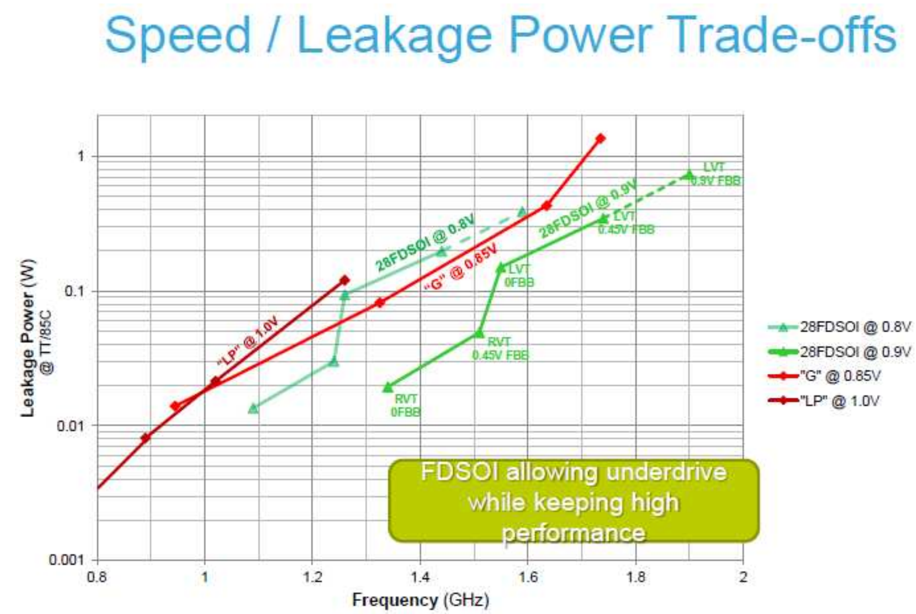
'*Wireless Industry Trends and Technology*' , *Bill Krenik*, Senior Director, Advanced Technology, *Texas Instruments*, BWRC 2007 Winter retreat, 8 January 2007

- Can ***SOI technology*** help to achieve ***better cost/performance/consumption tradeoff*** ?

SOI CMOS for Application and Baseband Processor

- In order ***to address*** both ***applications processor*** and ***baseband processor challenges***, ***ST*** is ***committed to Fully Depleted-SOI technology***.
- ST believes that ***FD-SOI*** can deliver the ***best speed/power performances ever***.

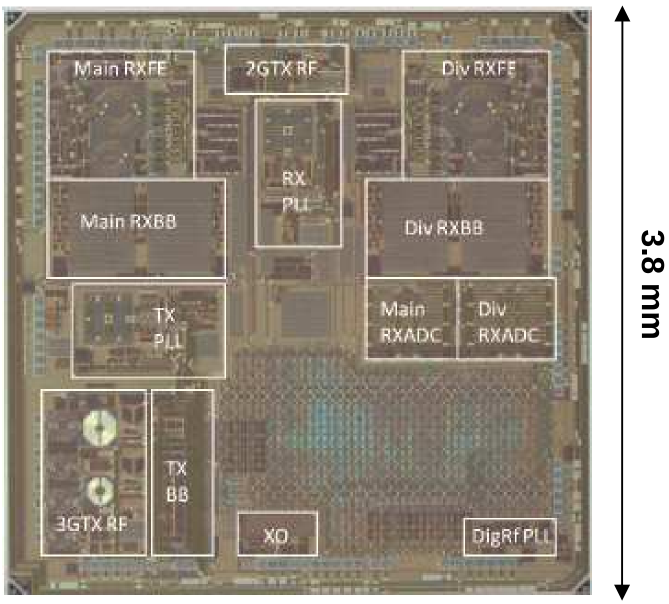




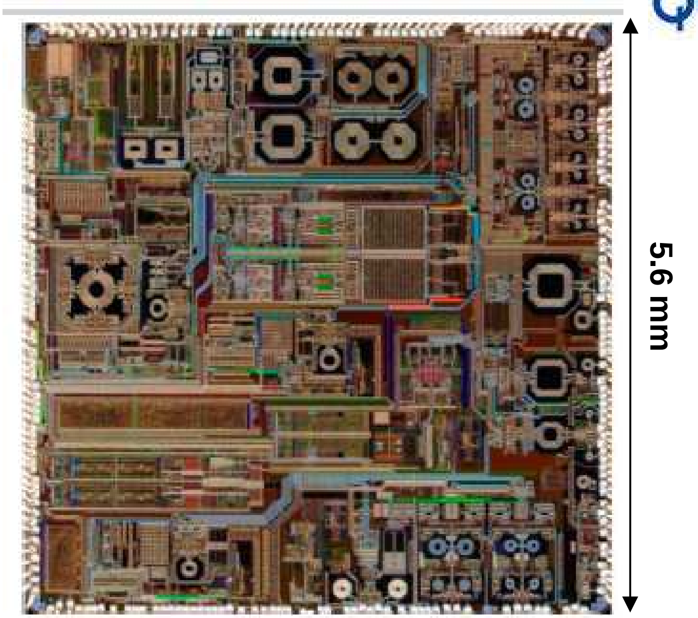
"28 and 20 nm FDSOI Technology Platforms'", Giorgio Cesana, SOI Consortium (www.soiconsortium.org), February 2012.

3G RF Transceiver Challenges

- ***RF*** cellular ***transceiver*** has also achieved a very ***high level of integration*** (with ***65 nm SOC*** available on the market).



M. Nilsson et al., "A 9-band WCDMA/EDGE transceiver supporting HSPA evolution", IEEE International Solid-State Circuits Conference (ISSCC), 2011, Page(s): 366 - 368

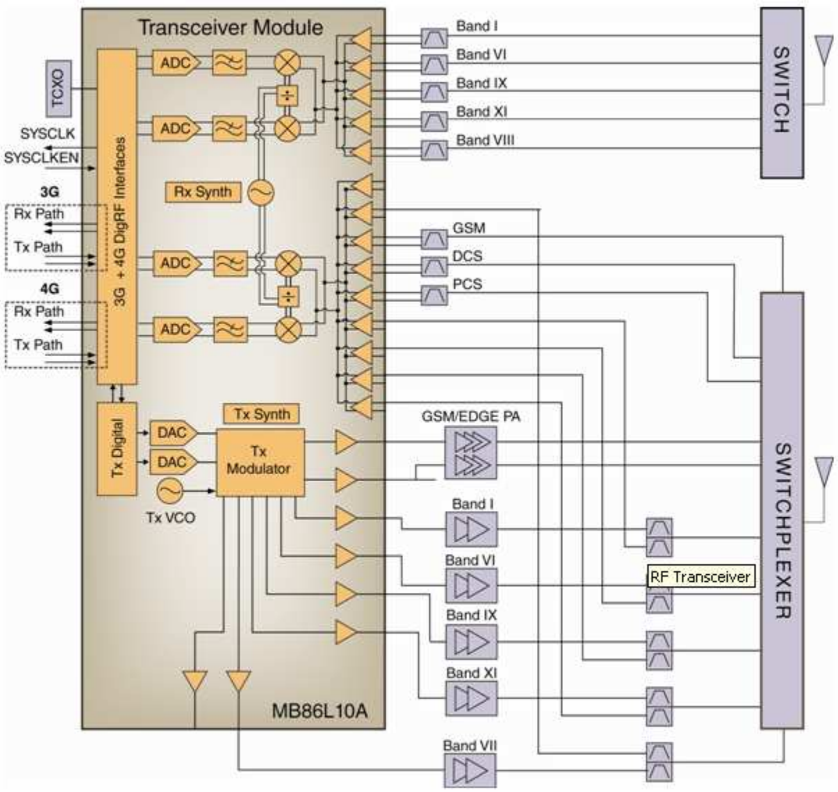


A. Hadjichristos et al., "Single-chip RF CMOS UMTS/EGSM transceiver with integrated receive diversity and GPS", IEEE International Solid-State Circuits Conference (ISSCC), 2009, Page(s): 118 - 119

- But since ***RF and analog parts*** consume the ***main part of die***, moving to technology ***beyond 65 nm*** does ***not*** bring ***necessary any economical advantage***.

3G RF Transceiver Challenges

- With the ***support of new bands*** and the ***integration of new features*** such as ***antenna diversity,*** the ***design of advanced RF transceiver*** becomes even ***more challenging*** and the ***die size has to increase***.



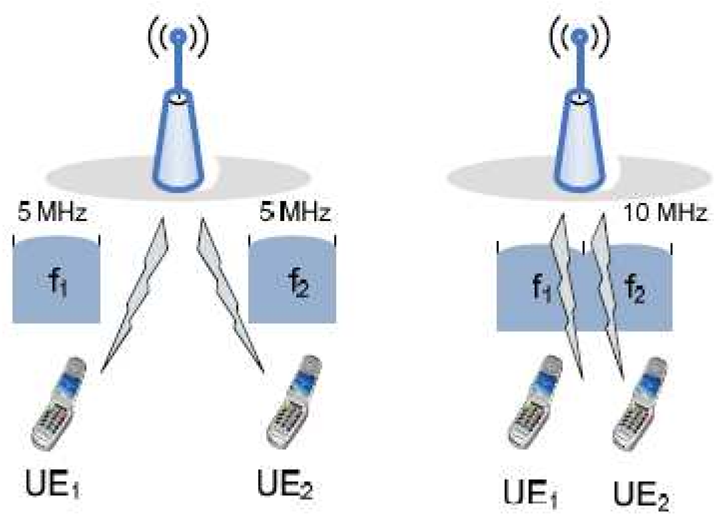
- GSM bands: ***GSM850***, ***EGSM900***, ***DCS1800***, ***PCS1900***
- ***WCDMA bands***: ***I, II, III, IV, V, VI, VIII, IX, X*** and ***XI***
- ***LTE bands***: ***1, 4, 7, 13, 17***
- ***14 differential RF inputs*** for the receiver
  - ***9*** differential RF inputs on the ***primary receiver***
  - ***5*** differential RF inputs on the ***diversity receiver***
- ***8 RF outputs*** on transmitter
- ***DigRF*** 3G and 4G ***interfaces to the baseband IC***
- Auxiliary ***SPI to control PAs***, switching regulators and ***antenna switch***

http://www.fujitsu.com/us/services/edevices/microelectronics/rftransceiver/l10/

3G RF Transceiver Challenges

- Moreover, since ***higher data rate*** are ***requested*** (***100 Mbps***) the wireless industry will have to support ***carrier aggregation for LTE***.

Single carrier versus Dual-Carrier Transmission



Eiko Seidel, Junaid Afzal, Günther Liebl, Nomor Research GmbH, "White Paper – Dual Cell HSDPA and its Future Evolution", January 2009.

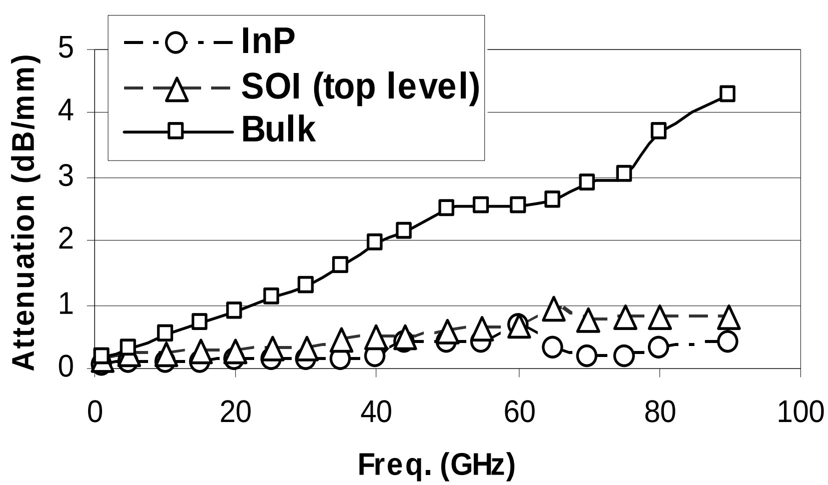
- This means that the ***power consumption*** of LTE ***RF transceiver*** will be the ***key feature to be optimized*** in the coming years.

SOI CMOS and RF Transceiver

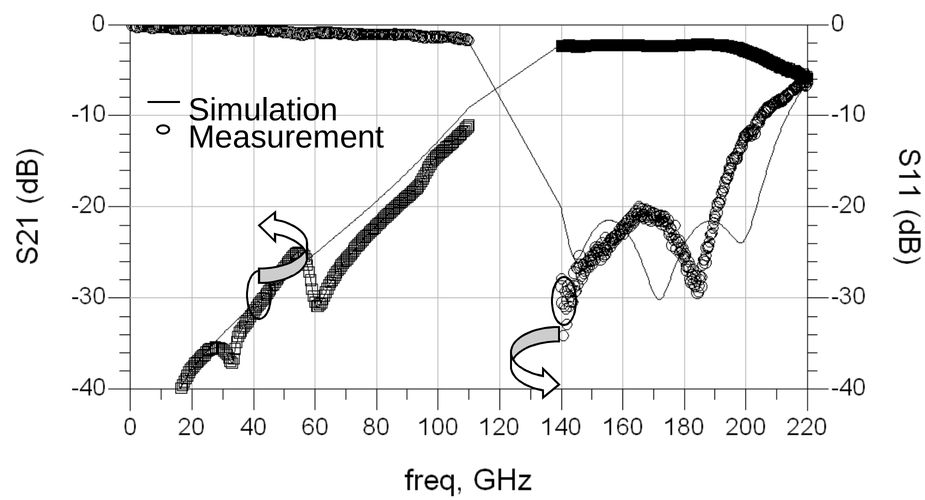
- Integration of ***high quality passive*** components in standard ***bulk silicon*** technology is ***not obvious*** (due to the use of lossy silicon substrate) and limits RF transceiver performances (consumption, sensitivity, output power,…).

- Thanks to the dielectric isolation offered by buried oxide, ***we can use High Resistivity (HR) substrate in SOI Technology***.

CPW transmission line performances on SOI



180 GHz CPW filter achieved on SOI

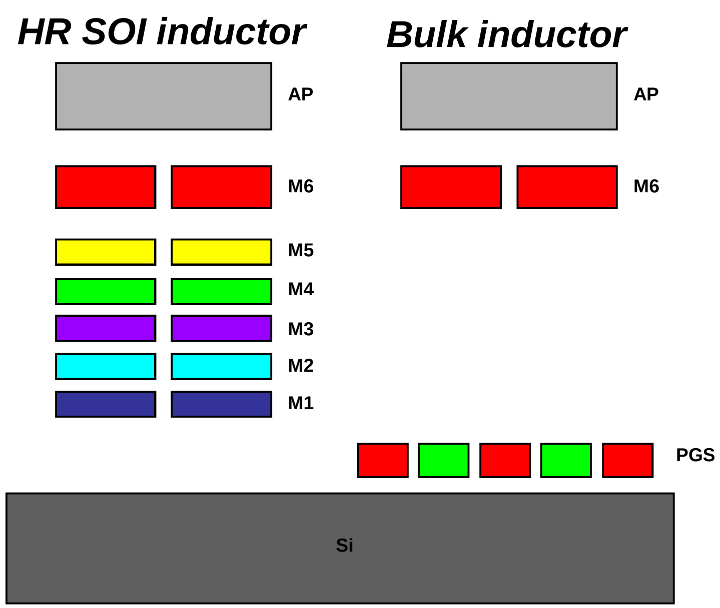


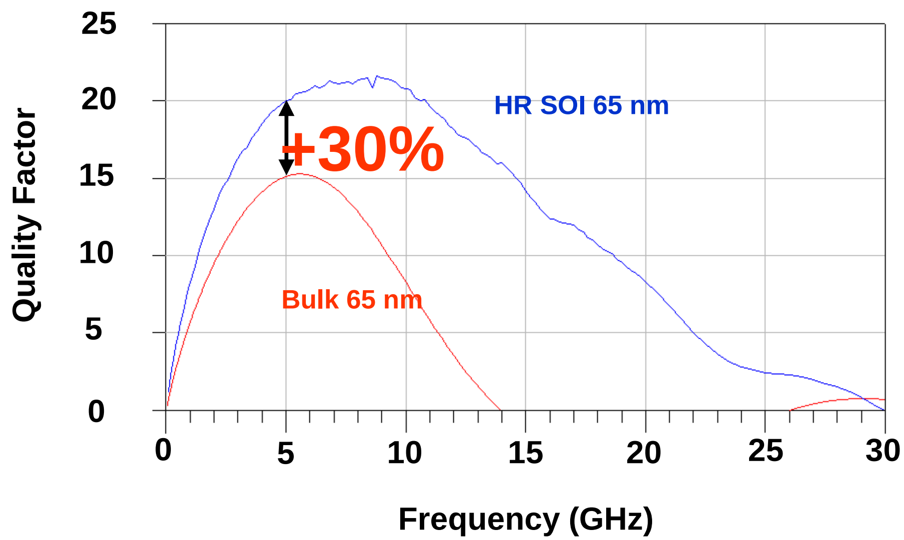
- ***Then, measured losses on HR SOI are comparable with InP***, which is a key advantage in order to improve RF transceiver performances.

SOI CMOS and RF Transceiver

- ***High quality factor inductors*** are ***mandatory*** for most of RF applications. However, it becomes harder and ***harder to offer*** such components in ***advanced standard CMOS technology*** due to ***BEOL evolution***.

→ ***HR SOI CMOS*** enables to achieve ***Q~20@5GHz*** in ***65 nm BEOL***, which is not feasible in bulk ***without Thick Copper*** option



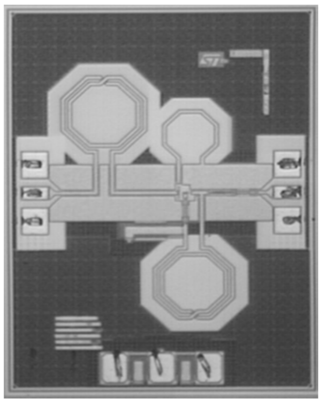


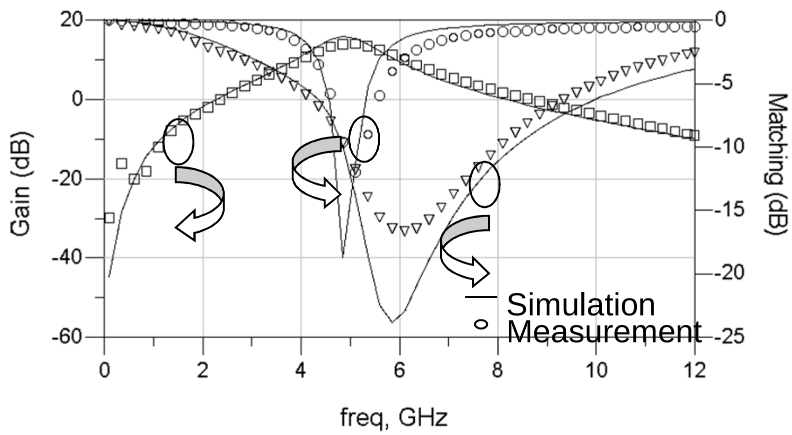
Benchmarking of ***0.82 nH*** inductors achieved in ***65 nm bulk and HR SOI technologies***

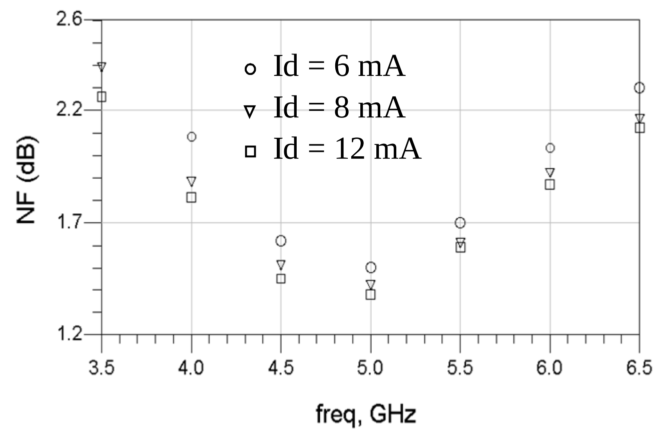
"On the Design of High Performance RF Integrated Inductors on High Resistively Thin Film 65 nm SOI CMOS Technology", F. Gianesello et al., IEEE Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems 2008, SiRF 2008, pp. 98 - 101, 23-25 Jan. 2008

SOI CMOS and RF Transceiver

- ***SOI optimized*** integrated planar ***inductors*** have been ***used for the design of a 5 GHz Low Noise Amplifier***







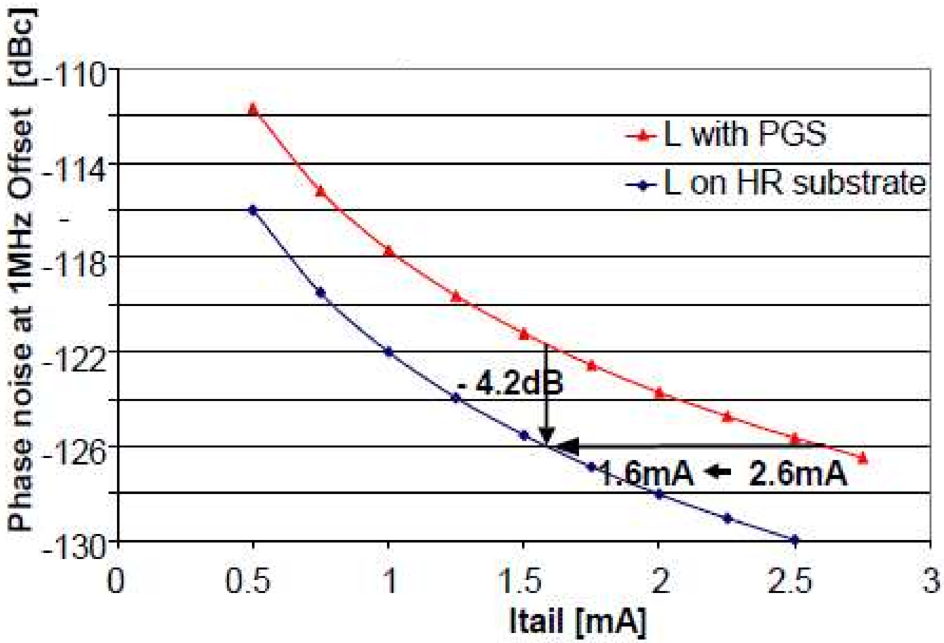
S_{21} = 14 dB, NF = 1.4 dB, S_{11} et S_{22} < -10 dB Id = 8mA and Vdd = 1.2 V

"5 GHz 1.4 dB NF CMOS LNA integrated in 130 nm High Resistivity SOI technology ", F. Gianesello, Daniel Gloria, Christine Raynaud, Samuel Boret, International Symposium on Integrated Circuits (ISIC-2007), 26 - 28 September 2007, Singapore

- ***State of the art performances*** have been measured, ***demonstrating*** the ***added value of SOI CMOS*** due to its ***compatibility with HR substrate***.

SOI CMOS and RF Transceiver

- ***Equivalent results*** have been obtained on a ***5 GHz VCO***, improved inductor quality factor achieved on ***SOI CMOS inductor*** helps to ***improve achievable noise figure*** (***or reduce*** the ***power consumption***)



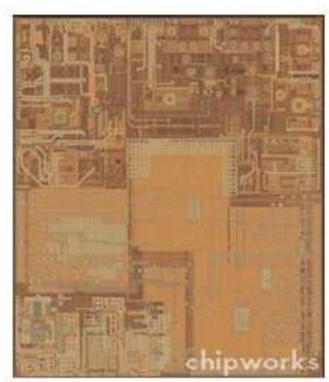
"A low-power 5 GHz CMOS LC-VCO optimized for high-resistivity SOI substrates", P. Delatte et al., page(s): 395- 398, IEEE ESSCIRC 2005,

- This could be a ***key advantage for 3G RF transceivers*** design, especially concerning ***wideband and high performance VCO design*** (which is a key challenge).

Combo Connectivity Chip Challenges

- ***Connectivity*** features (WiFi, Bluetooth, FM Radio and GPS) are now a ***commodity*** and then a ***high level of integration*** has been achieved in order to deliver ***cost effective combo chip solution*** through a ***SOC approach***.

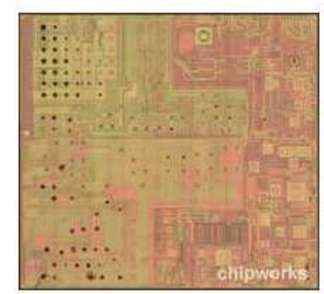
http://www.chipworks.com/



Broadcom ***BCM 4329*** die (***65 nm***)

33% **die** ***size reduction***

http://www.chipworks.com/



Broadcom ***BCM 4330*** die (***40 nm***)

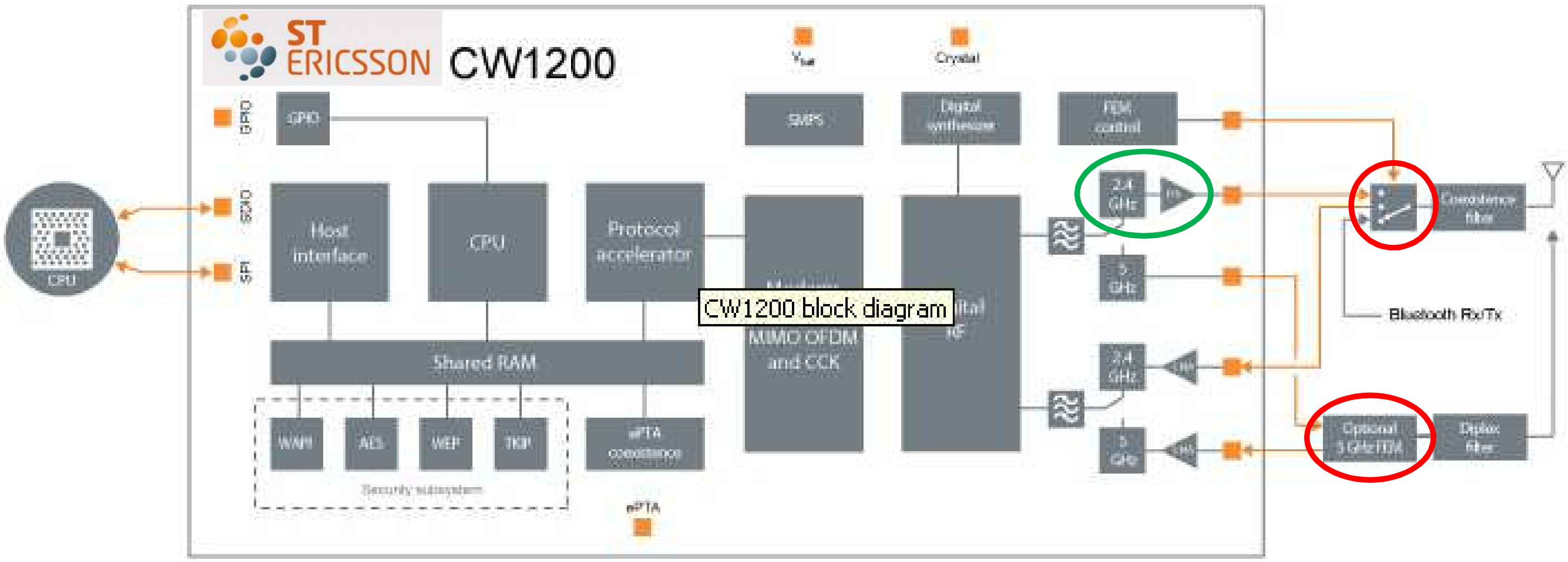
- But ***beyond 40 nm***, the ***economical gain*** is ***not obvious to demonstrate:***

"***28nm is the first process shrink which doesn't deliver a cheaper chip*** ... unless you need the advanced process because of performance reasons or die-size reasons, you're not going to get a cost benefit from converting to the new node"

Scott McGregor, CEO of Broadcom

Combo Connectivity Chip Challenges

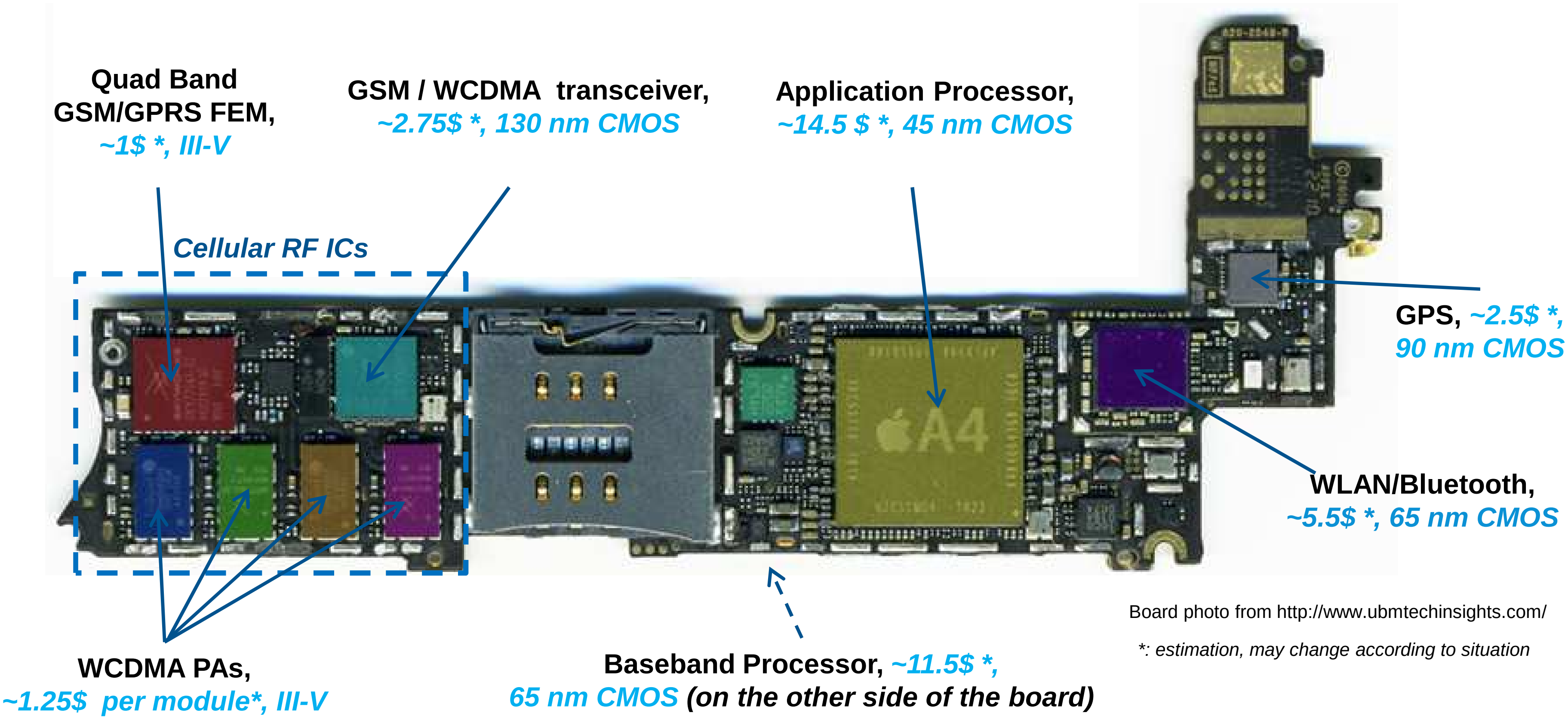
- Moreover, since ***connectivity*** is now a commodity, main players are trying to ***differentiate*** themselves by ***integrating the last off chip features*** (2.5 GHz PA, …).



http://www.stericsson.com/products/cw1200-wlan.jsp

- The ***two remaining key blocks,*** not yet integrated in CMOS, are the ***5 GHz PA*** and the ***SP3T antenna switches***. Then, ***if SOI CMOS*** technology demonstrates any ***advantage*** concerning the ***integration of FEM on silicon,*** the ***advantage for connectivity chip would then be obvious***.

Front End Module Challenges



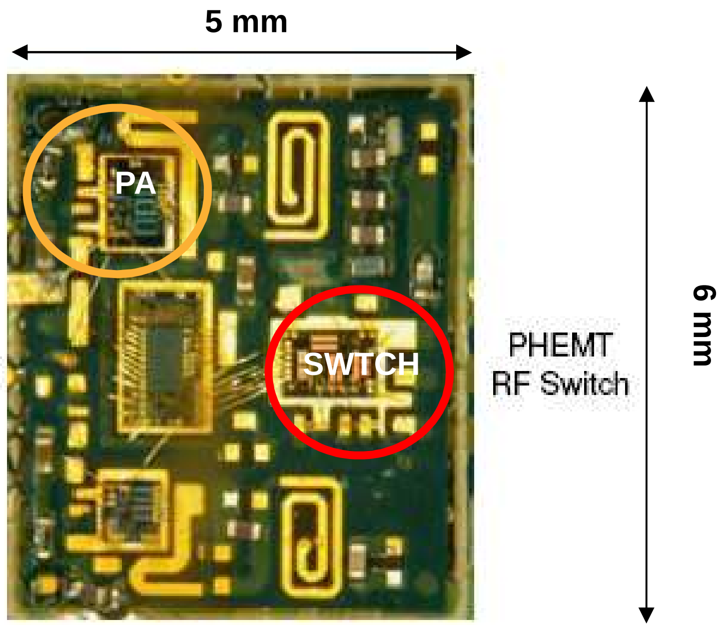
Board photo from http://www.ubmtechinsights.com/

*: estimation, may change according to situation

- ***Most of the cost*** of the cellular ***RF ICs*** are ***in the FEMs*** (***~70%*** of the RF BOM), ***the level of integration of FEM has to be improved*** in order to achieve both ***lower cost*** and ***reduced PCB area*** (which is a key concern in densely packaged smartphones).

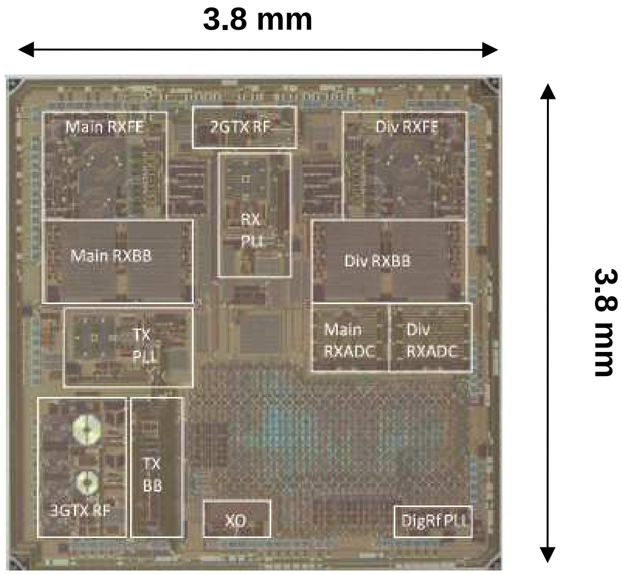
Front End Module Challenges

GSM FEM:



2.5G RF TX (transmit) module for cellular (GSM) applications (6mm x 5mm) –
C. Raynaud et al., SOI Conference Short Course 2007

3G RF Transceiver:

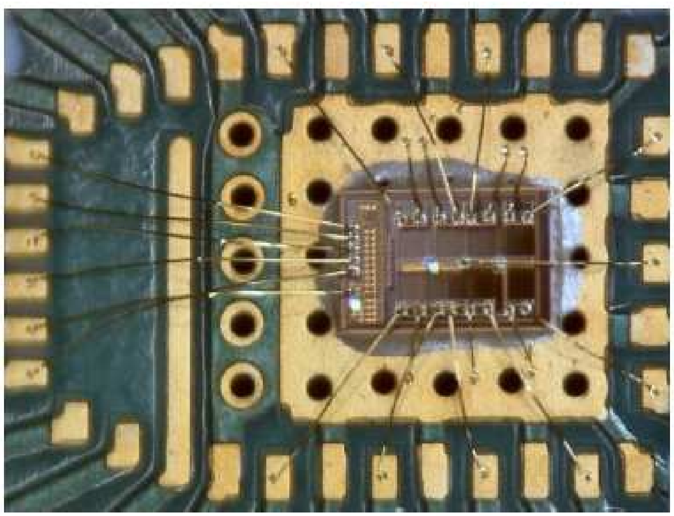


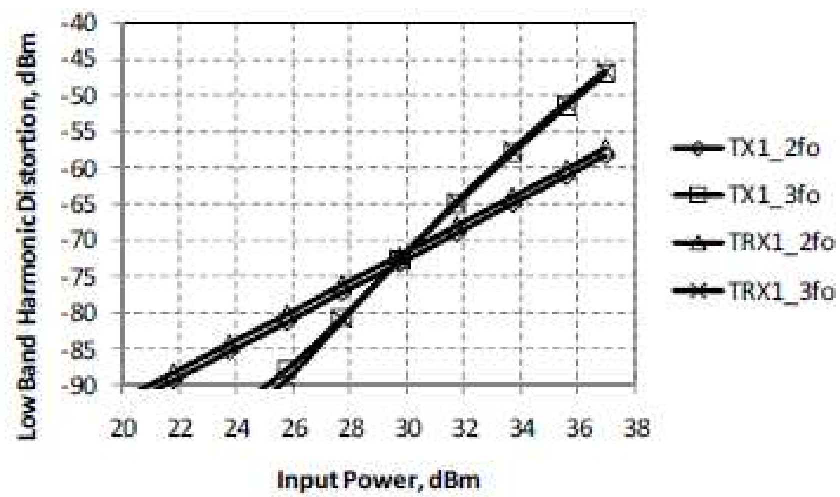
M. Nilsson et al., "A 9-band WCDMA/EDGE transceiver supporting HSPA evolution", IEEE International Solid-State Circuits Conference (ISSCC), 2011, Pages: 366 - 368

- ***FEM*** are still using a module making an ***assembly*** of a ***variety of technologies*** (***III-V*** HBT, ***IPD***s, ***LTCC*** and ***CMOS***). ***FEM*** is now the ***only space*** in a RF system where ***integration can be*** greatly ***improved,*** can ***SOI CMOS*** play help to ***integrate FEM on silicon***?

SOI CMOS and Front End Module

- Since most of the complexity and cost are in the FEMs, a lot of researches have been performed during past years in order to ***improve the integration level of FEM*** and to ***use CMOS technology as much as possible to lower cost***.
- In this quest, the ***integration of the antenna switches on SOI*** has played a key role, mainly because this key block is known as ***not feasible in Bulk CMOS***. ***SOI antenna switches*** have now demonstrated their ability to deliver the appropriate performances with a cost effective approach.

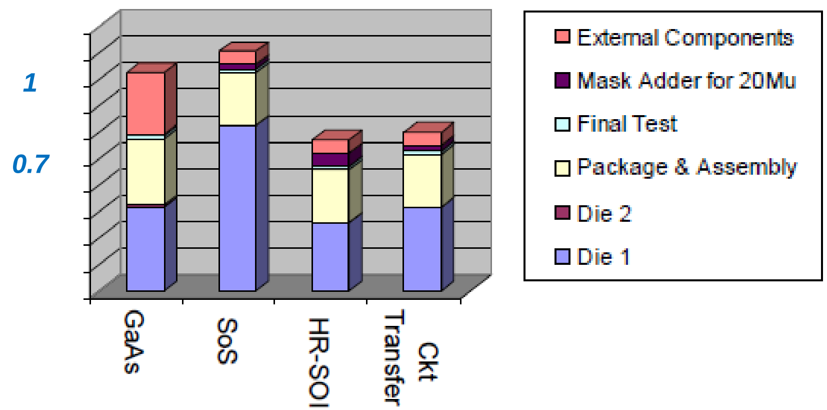


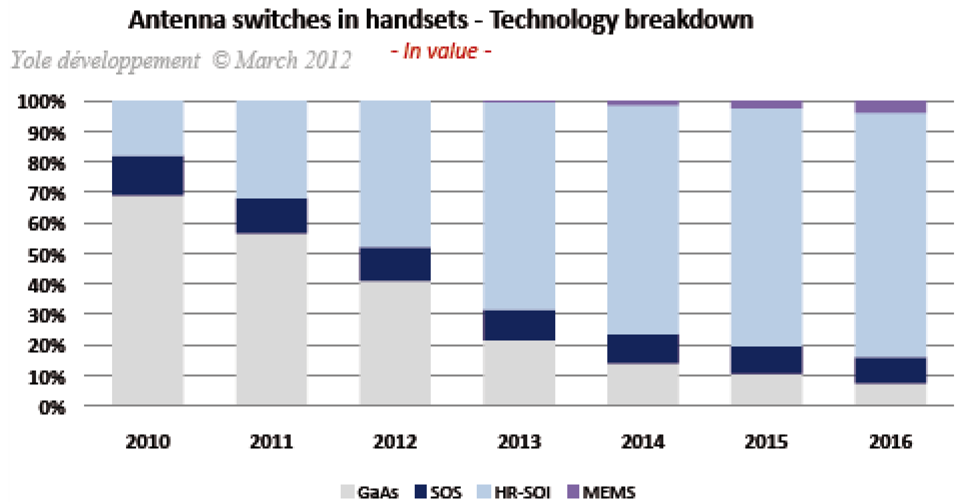


"Cellular antenna switches for multimode applications based on a Silicon-on-Insulator technology", A. Tombak et al., Radio Frequency Integrated Circuits Symposium (RFIC), 2010 IEEE, Page(s): 271 - 274

SOI CMOS and Front End Module

- ***SOI adoption by leading FEM manufacturer*** in order to deliver ***SOI antenna switches is already a reality***.
- Main ***FEM manufacturers*** (RFMD, Skyworks, …) are ***currently delivering millions of CMOS SOI antenna switches*** to the market.





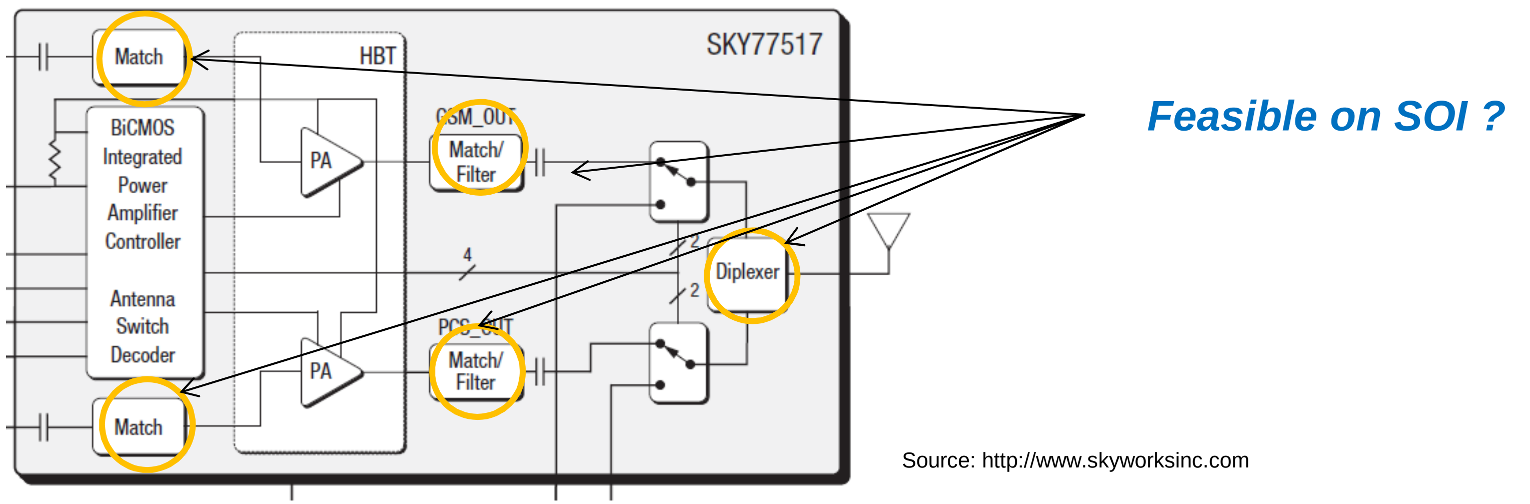
"SOI Substrate for RF Applications", E. Desbonnets, EuroSOI 2010 Tutorial, Grenoble, 25-27 January 2010.

Cost has been the first motivation to move antenna switches business on SOI

SOI CMOS and Front End Module

- Moreover, as we can see below, ***FEM design is all about passive*** (which have been up to now integrated using LTCC or IPD technologies).

Dual Band GSM/GPRS FEM



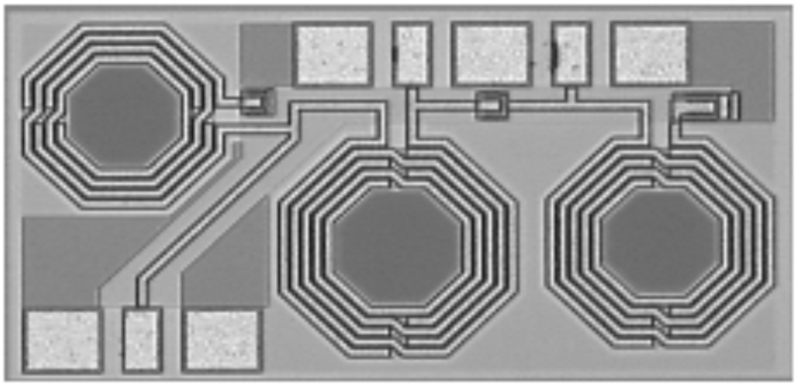
Source: http://www.skyworksinc.com

- Since ***SOI*** is ***fully compatible with High Resistivity (HR) substrates***, ***high performance passive*** components can be integrated on SOI.

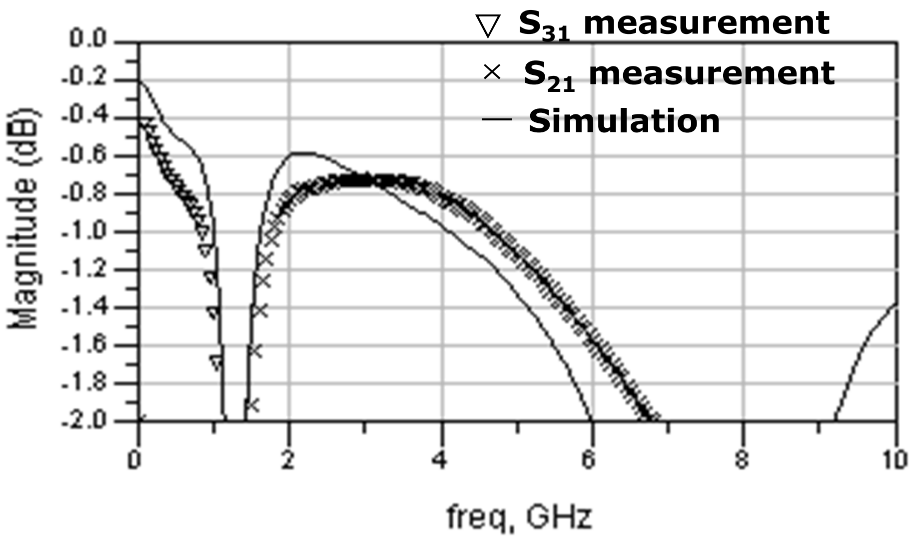
- Then, we can think about ***lowering the cost of FEM*** by directly ***integrating FEM passive functions*** (harmonic filters, diplexer, balun, …) ***on SOI along with antenna switches***.

SOI CMOS and Front End Module

- A ***GSM/DCS diplexer*** has been successfully designed in ST 130 nm SOI CMOS technology, achieving a very compact form factor.



~0.45 mm²



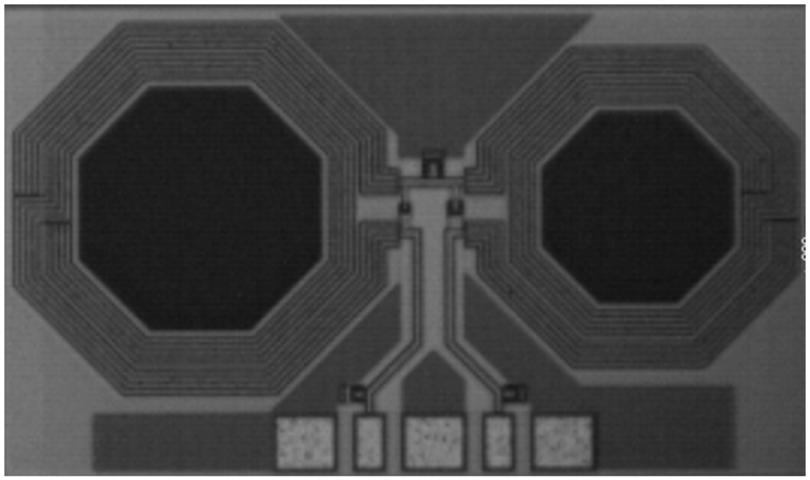
"Integration of cellular front end modules on advanced high resistivity SOI RF CMOS technology", F. Gianesello et al., 2011 IEEE Topical Conference on Power Amplifiers for Wireless and Radio Applications (PAWR), pp. 29 - 32, 16-19 Jan. 2011

- ***Excellent agreement is obtained between simulation and measurement*** (confirming the accuracy of inductor scalable models available in ST design kit).

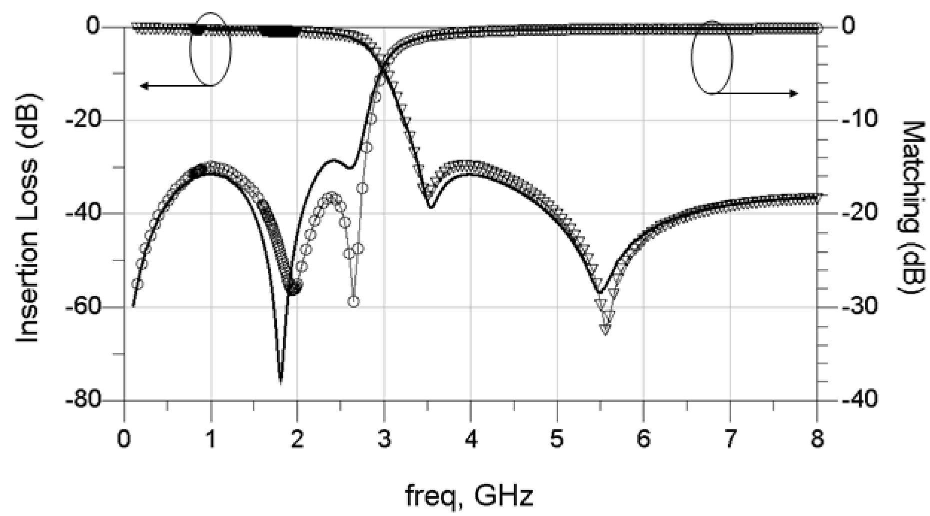
- ***Promising performances*** have been achieved, ***insertion losses in both bands are < 1 dB,*** which is clearly competitive with current LTCC or IPD solutions.

SOI CMOS and Front End Module

- A ***DCS harmonics filter*** has been successfully designed in ST 130 nm SOI CMOS technology, achieving a very compact form factor.



~0.87 mm^2



"Integration of multi-standard front end modules SOCs on high resistivity SOI RF CMOS technology", F. Gianesello et Al., Radio Frequency Integrated Circuits Symposium (RFIC), 2010 IEEE, Pages: 229 - 232

- ***Excellent agreement is obtained between simulation and measurement*** (confirming the accuracy of inductor scalable models available in ST design kit).
- ***Promising performances*** have been achieved, ***insertion losses < 1 dB @ 1980 MHz,*** which is clearly competitive with current LTCC or IPD solutions.

SOI CMOS and Front End Module

- The ***integration of PA on SOI*** is the ***next step*** (and has already been demonstrated).
- Moreover ***CMOS technology*** has ***already demonstrated some capabilities*** on this topic:

Skyworks (formerly Axiom) AX502 GSM/GPRS Quad Band CMOS Power Amplifier

50+ Millions Units shipped in 2009

100 Millions Units milestone in 2012

Amalfi Stratos™ EDGE – AM8901 High Efficiency GSM/EDGE Quad-Band CMOS Power Amplifier

Javelin JAV5001 3G Band I CMOS PA Family

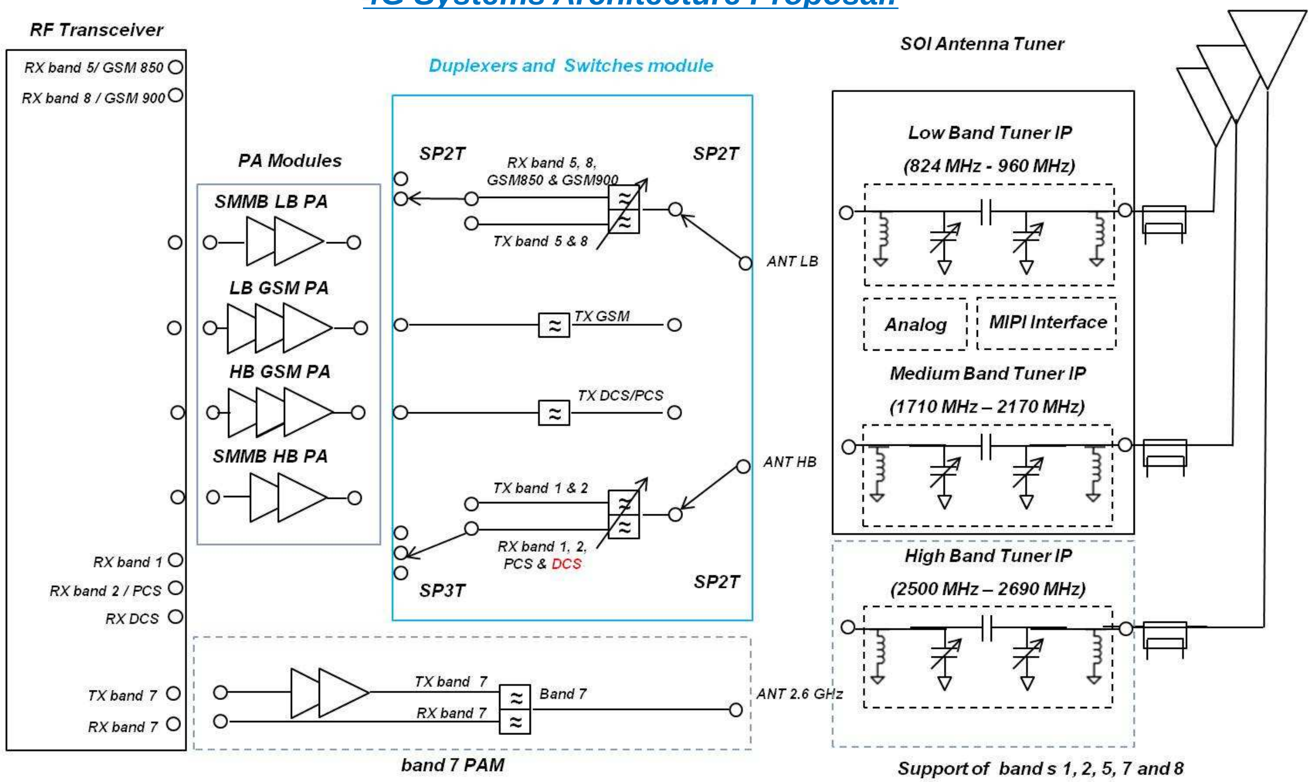
Black Sand BST34 Series CMOS 3G Power Amplifiers

- Then, the ***integration of the whole FEM on CMOS SOI is just natural*** since it is the ***only demonstrated practical path to deliver low cost 4G FEM SOC in CMOS***.

4G Architecture Trends

- ***SOI CMOS*** technology has clearly demonstrated to be a ***useful technology*** in order to ***address current challenges*** faced by the wireless industry. But ***what about the future***:

4G Systems Architecture Proposal:

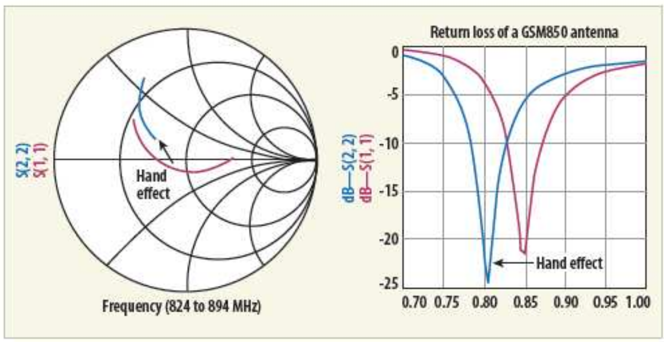


- RF transceiver is already largely reprogrammable, ***introducing agility in the FEM is the next step*** (***converged PA***, ***antenna tuner*** and ***tunable duplexer*** are the key topics).

CMOS SOI for the future ?

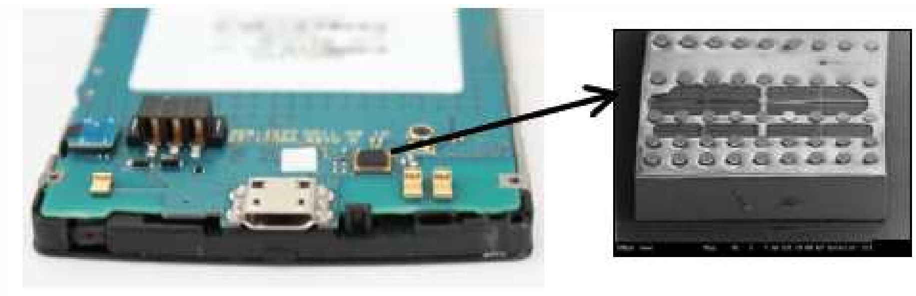
Antenna Tuner (1/2):

- ***Antenna tuner*** features for ***high end smartphone*** is actually a hot topic



2. Hand effects typically detune antenna resonant frequency downward and cause significant mismatch at the intended operating frequency.

Tero Ranta & Rodd Novak, "Antenna Tuning Approach Aids Cellular Handsets", Microwave & RF, November 2008.



Wispry RF MEMS antenna tuner in Samsung Focus Flash and die SEM view (source System Plus Consulting)

"RF Filters, PAs, Antenna Switches & Tunability for Cellular Handsets - web flyer", Yole Développement, Market , applications & Technology report – April 2012

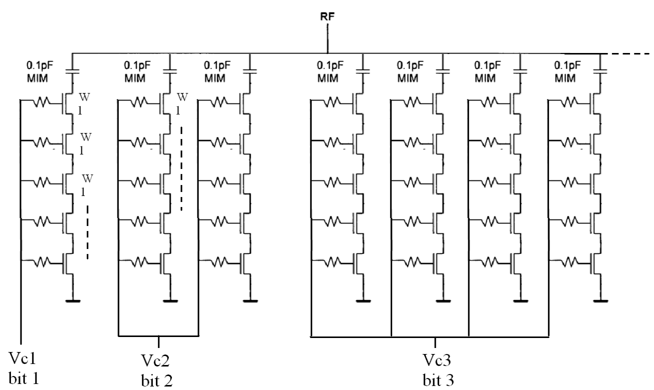
- The ***goal of antenna tuner*** is to ***ensure that the antenna system will always deliver 50 Ω to the RF system*** whatever the environment is (for example user hand has a strong impact on ***antenna detuning*** which turns in increasing losses due to mismatch between the antenna and the SAW filter/Duplexer).

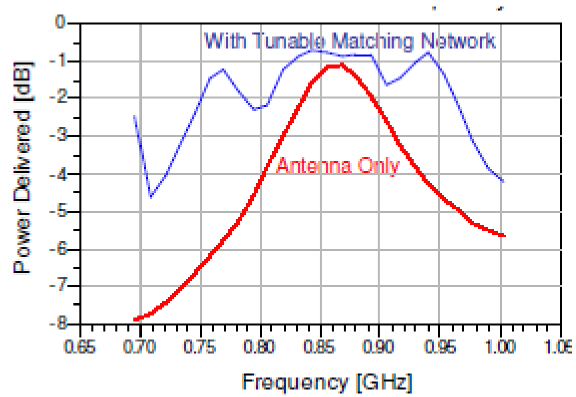
- ***BST technology*** (Agile RF, Paratek), ***MEMs technology*** (Cavendish Kinetics, wiSpry), ***SOS technology*** (Peregrine) and ***SOI CMOS*** (STMicroelectronics, IBM) are ***currently evaluated*** in order to introduce first antenna tuner solution to the market.

CMOS SOI for the future ?

Antenna Tuner (2/2):

- Leveraging ***SOS/SOI antenna switches experience***, the ***development of high power*** (and ***high linearity***) ***Digitally Tuned Capacitor*** (DTC) is on its way (for example Peregrine Dune™ technology).
- The ***advantage*** of the ***antenna tuner*** has already been ***demonstrated practically***, ***especially*** at lower frequency (***700 MHz*** band use for ***LTE in the US***).





R. Whatley, T. Ranta,D. Kelly, "CMOS Based Tunable Matching Networks for Cellular Handset Applications", 2011 IEEE MTT-S International Microwave Symposium Digest (MTT), Baltimore, 5-10 June 2011.

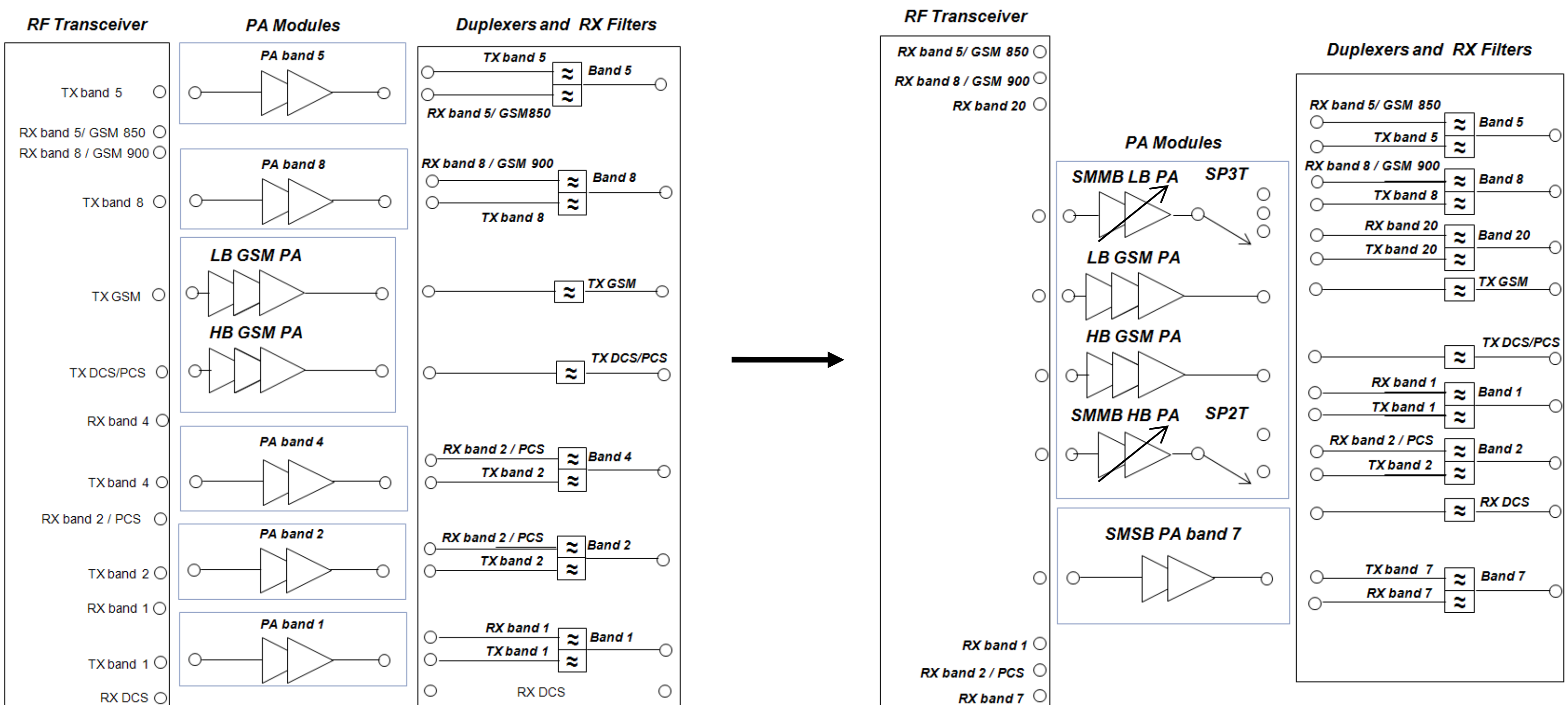
- ***RF MOSFETs are stacked for power handling capability*** (today 5 MOS for ~ 32 dBm under 50 Ω). This ***SOI CMOS DTC component***, could ***play a key role*** in the ***development of tunable FEM*** in order to ***deliver low cost*** and ***highly integrated chipset solution*** for ***4G mass market*** smartphones.

CMOS SOI for the future ?

Converged PA (1/2):

- Moving to 4G, it would ***not*** be ***practical to add new PA modules*** in order ***to support additional frequency bands***. To address this problem, ***converged PA solution has emerged*** during the past years.

3G Systems Architecture: → **4G Systems Architecture:**

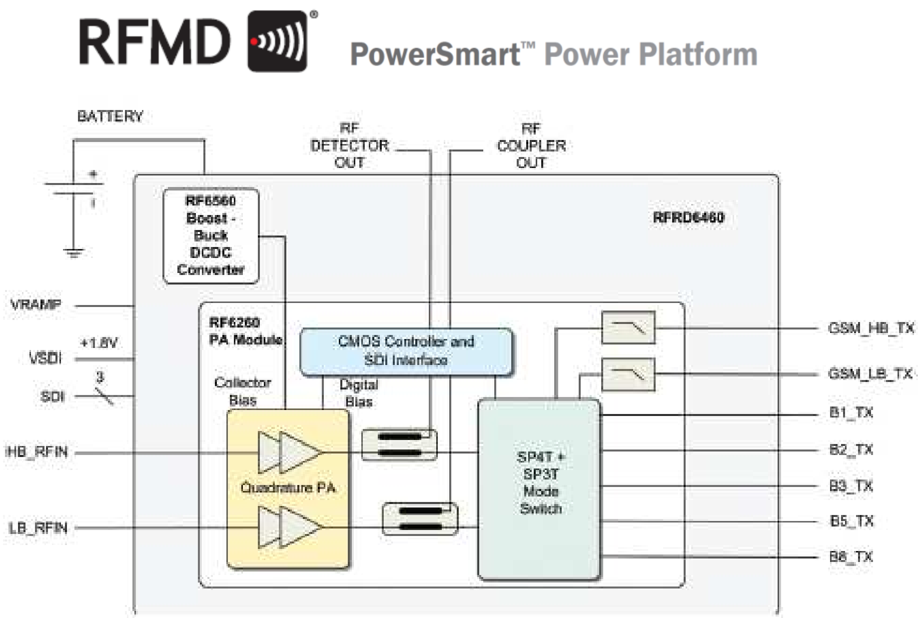


Support of bands 1, 2, 5, 7, 8 and 20

CMOS SOI for the future ?

Converged PA (2/2):

- ***Converged PA*** is now seen as the ***most realistic way to handle a high number of frequency bands*** in a cost effective manner (***reducing the number of required PA to 2***). Moreover, the solution has ***already proved to be practical in volume***.



Source: http://www.rfmd.com

10 Millions Units since April 2011

Samsung Galaxy S2

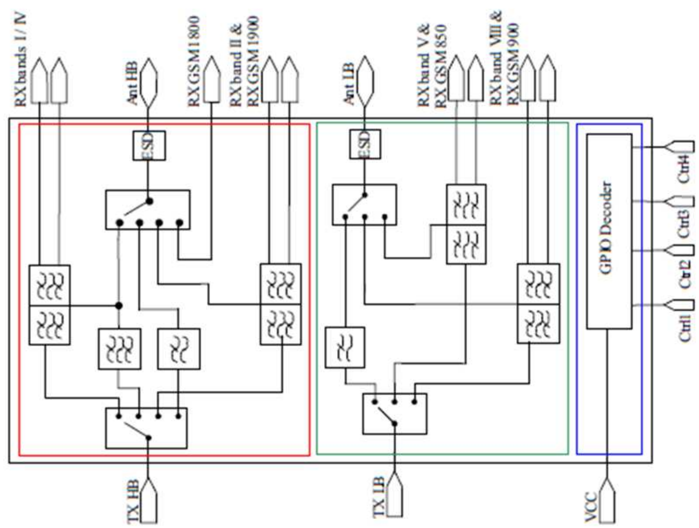
1st smartphone to use a converged PA

- The ***key point*** in converged PA design concern the support of the ***tunable matching network*** and ***mode switches***. ***SOI*** could enable here the ***full integration in CMOS*** in order to ***lower the price of the solution***.

CMOS SOI for the future ?

Tunable Duplexer (1/2):

- Moving to ***converged PA***, the ***SAW/BAW duplexer*** have now to be ***integrated in a single module*** (along with the antenna switches in some cases).



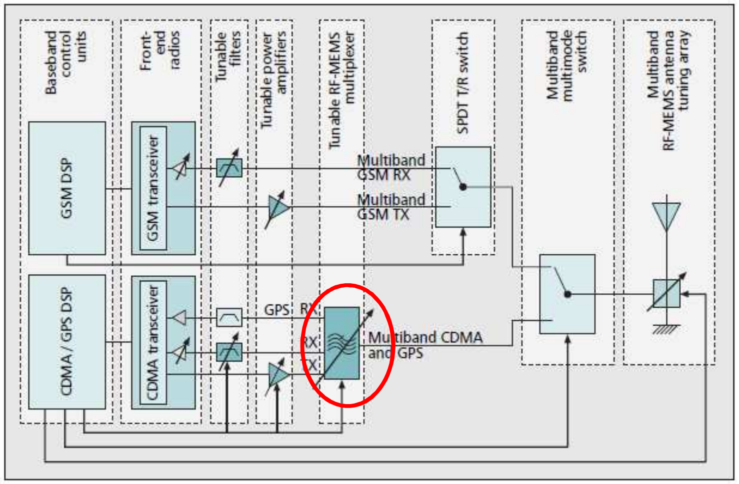
High performance microwave acoustic components for mobile radios Pitschi, F.M.; Kiwitt, J.E.; Koch, R.D.; Bader, B.; Wagner, K.; Weigel, R.; Ultrasonics Symposium (IUS), 2009 IEEE International Digital Object Identifier: 10.1109/ULTSYM.2009.5441550 Publication Year: 2009 , Page(s): 1 - 10

- Moving to ***4G***, this ***multimode duplexer module*** will reach a ***size*** which would be ***difficult to manage***.

CMOS SOI for the future ?

Tunable Duplexer (2/2):

- That is why, we can see now some ***new developments to achieve tunable duplexer*** (several duplexer are replaced by a tunable one over a given frequency band).



RF-MEMS for Wireless Communications, Hilbert, J.L.; Communications Magazine, IEEE Volume: 46 , Issue: 8, 2008 , Page(s): 68 - 74

- So basically, the goal is to develop ***tunable filters using high power SOI CMOS Digitally Tunable Capacitor*** (as for the antenna tuner).

- It is clearly ***not easy to achieve*** (since narrow band pass filter have to be achieved), ***but looks feasible*** and it is clearly the ***next integration step to be achieved***.

Conclusion & Perspective

- ***Wireless*** technology is now clearly one of the ***key drivers*** of the ***semiconductor industry***.
- Up to now, conventional bulk ***CMOS technology*** has been able to ***address*** the need of the ***wireless*** industry thanks to ***aggressive scaling roadmap***.
- From the ***digital point*** of view, ***FD-SOI technology*** can offer a real ***breakthrough*** in order to deliver ***unprecedented speed / power performances tradeoff***. FD-SOI could then play a key role in the application processor and baseband processor businesses.
- From the ***RF point of view***, the ***rules of the game*** are ***changing***:
  - ***RF transceiver*** have ***already staled at more mature process nodes*** (e.g. 65 nm)
  - ***Connectivity combo chip*** future is ***not clear beyond 40 nm***
  - More generally, most of the ***value*** of the RF BOM and ***challenges rely with the FEM***
- ***FEM integration on CMOS SOI will be the key driver*** in order to accommodate with this new environment since it will enable ***cost effective 4G FEM solutions***. All FEM makers but also Chipset maker are engaged or engaging.
- This trend represents a promising ***opportunity*** for SOI in order to ***create added value*** through a « ***More than Moore*** » approach.

Thank You For Your Attention !