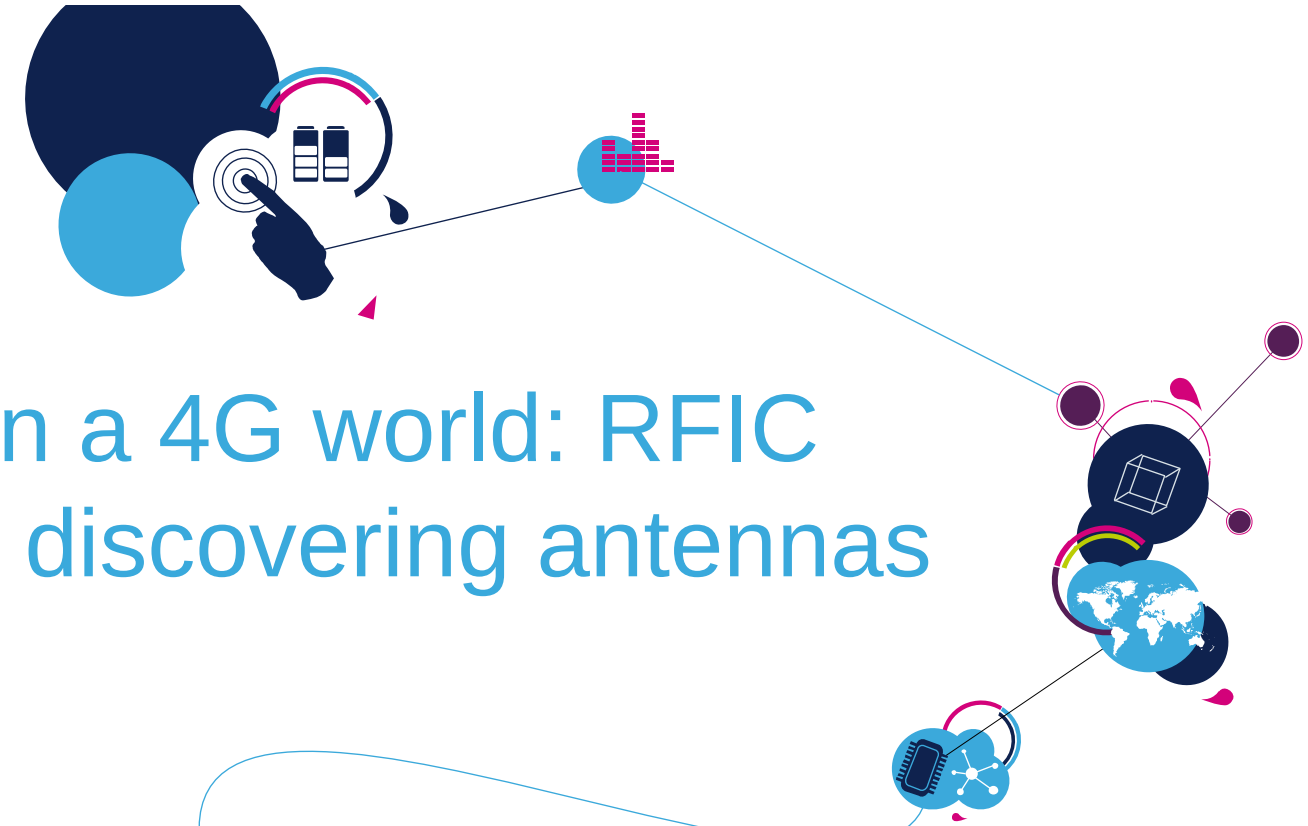


Innovate in a 4G world: RFIC designers discovering antennas

Fred Gianesello

STMicroelectronics, Technology R&D, Silicon Technology Development, Crolles, France

Tuesday, April 9
IL2.1: Invited Speaker 3

life.augmented

Why is ST attending to EuCAP ?

- Neither are we lost or did we come by chance:

→ Opportunity to bridge the gap between circuit and antenna communities in order to enable next wireless innovations

Outline

- Wireless Business Overview
- 4G wireless applications
  - 4G RFIC challenges
  - What about 4G antennas ?
  - Innovative 4G antenna leveraging circuit design techniques
- 60 GHz wireless applications
  - WiGig technology overview
  - Low cost 60 GHz antenna challenge
  - 60 GHz antenna has a business enabler: 4G small cells business case
- Conclusion and perspectives

Wireless Business Overview

- *Mobile phone* market is all about *smartphones*, in *4Q12* smartphones represent *45.5% of the market* (~219.4 millions units) an *increase of 36.4%* year-over-year.
- *But* smartphone is not the only force in action here, *tablet* is *also playing a key role* with *~33.8 Millions* tablet shipped in *1Q13* (*up 75.8%* year-over-year).

Apple iPhone 5

Worldwide Devices Shipments by Segment (Thousands of Units)

Device Type	2012	2013	2014	2017
PC (Desk-Based and Notebook)	341,263	315,229	302,315	271,612
Ultramobile	9,822	23,592	38,687	96,350
Tablet	116,113	197,202	265,731	467,951
Mobile Phone	1,746,176	1,875,774	1,949,722	2,128,871
Total	**2,213,373**	**2,411,796**	**2,556,455**	**2,964,783**

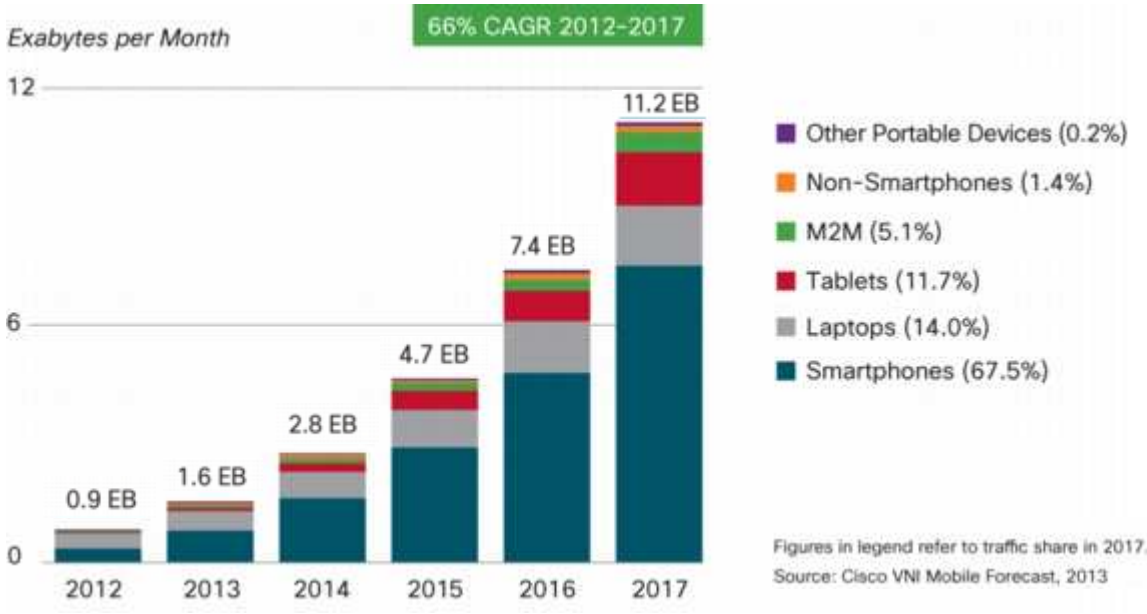
Source: Gartner (April 2013)

Apple iPad Mini

- We are *moving away from the PC area*, mobility/connectivity is everywhere.

Wireless Business Overview

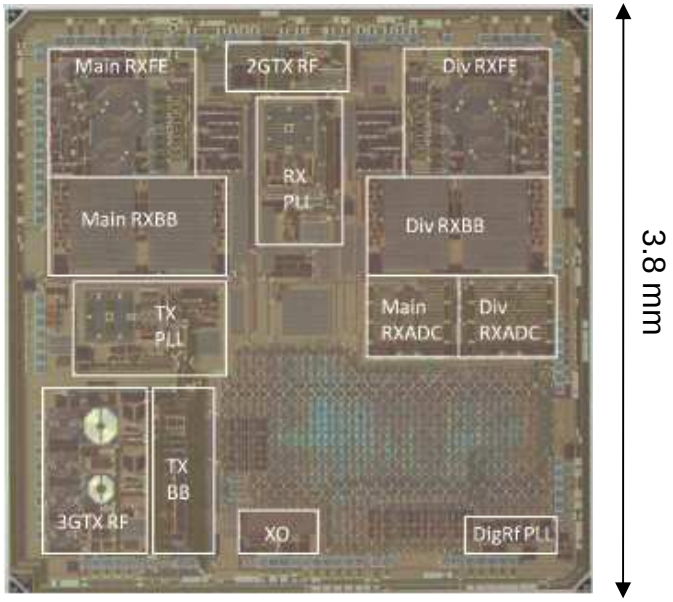
- Following the growth of mobile devices, *global mobile data traffic* is booming and will exceed this year *1.6 exabytes/month* in *2013*.



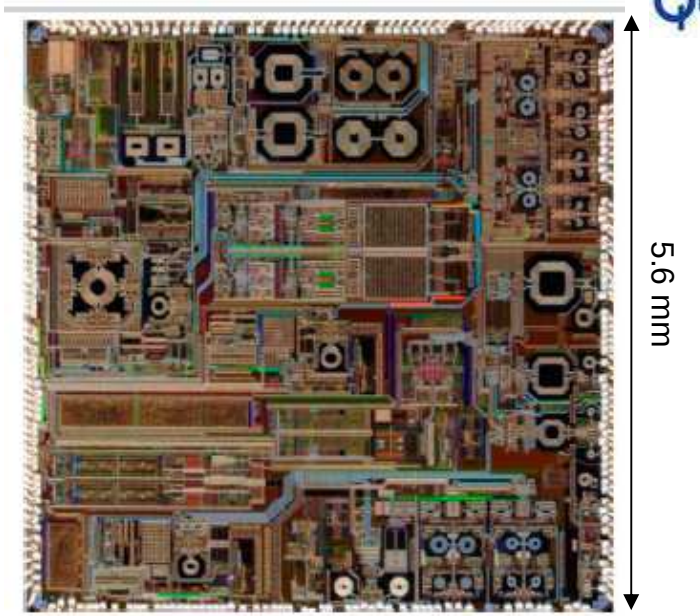
- To address this challenge, we will *focus here* on *2 wireless technologies*:
  - ***4G/LTE*** : deliver higher speed to smartphone/tablet users
  - ***60 GHz/WiGig*** : achieved cable speed (up to 7 Gb/s) wirelessly

Cellular RF CMOS Transceiver

- In order to *reduce costs*, highly integrated *RF* cellular *transceiver SOC* achieved in *CMOS technology* are available (mainly using 65 nm node).



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

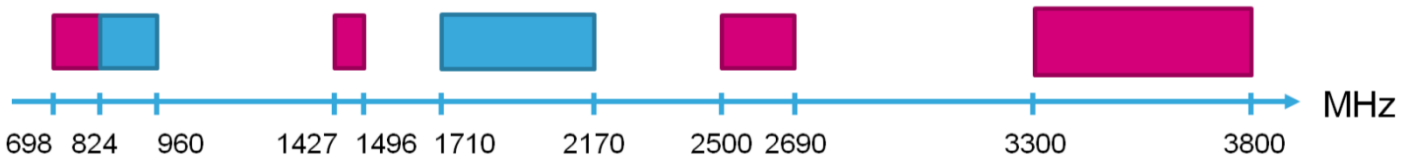


A. Hadjichristos et al., "Single-chip RF CMOS UMTS/EGSM transceiver with integrated receive diversity and GPS", IEEE International Solid-State Circuits Conference (ISSCC), 2009, Page(s): 118 - 119

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

4G Challenges

- So *many* new *bands* to be supported :

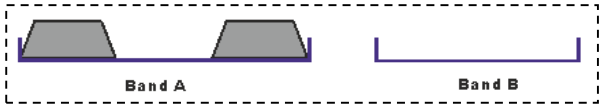


3G bands

LTE additional bands

- And *higher data rates* require to support *many bands at the same time*:

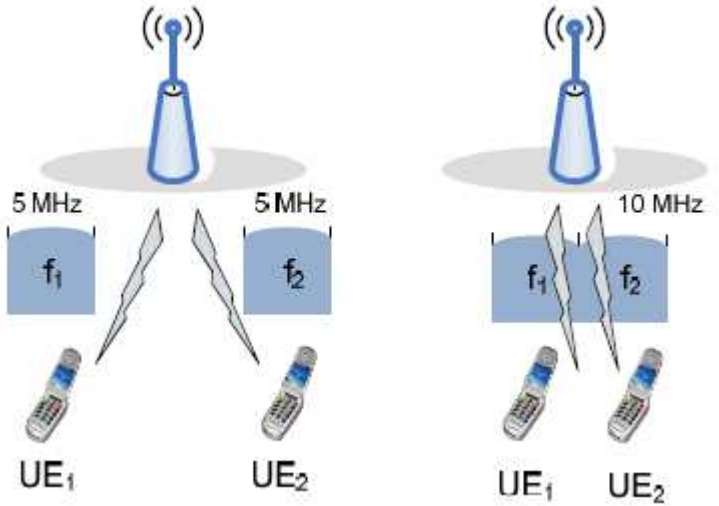
Intra-band *carrier aggregation*: contiguous component carriers



Intra-band *carrier aggregation*: non-contiguous component carriers

Inter-band *carrier aggregation*

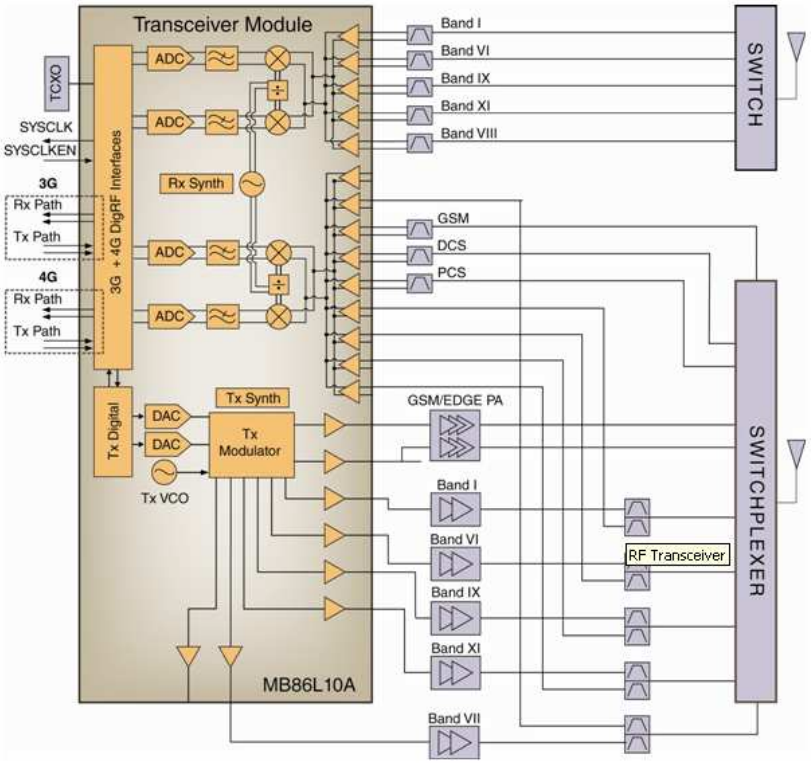
Single carrier versus Dual-Carrier Transmission



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

4G RF Transceiver Challenges

- Despite the complexity of 4G systems, *RF IC designers* have *managed so far* to leverage CMOS technology capability *to develop flexible RF transceiver*:

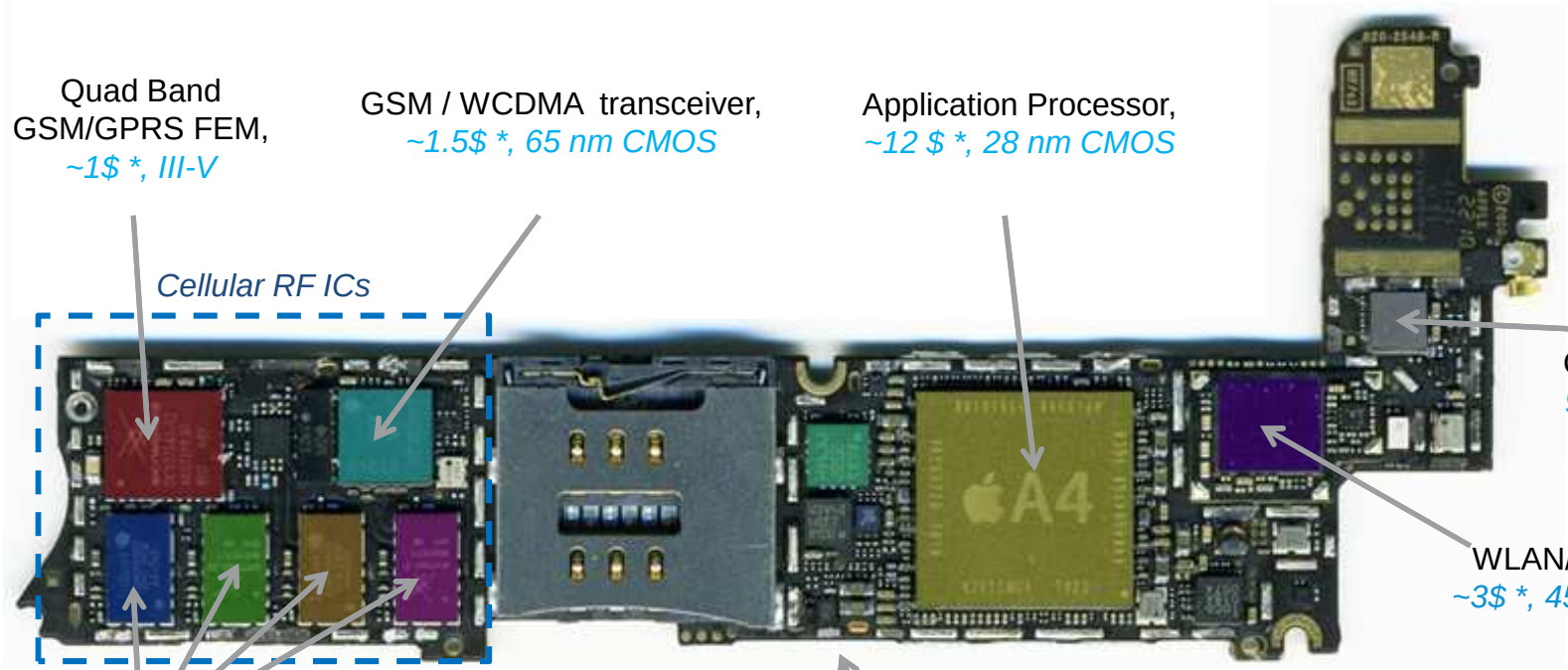


- GSM bands: *GSM850*, *EGSM900*, *DCS1800*, *PCS1900*
- *WCDMA bands*: *I, II, III, IV, V, VI, VIII, IX, X* and *XI*
- *LTE bands*: *1, 4, 7, 13, 17*
- ***14 differential RF inputs*** for the receiver
  - ***9*** differential RF inputs on the ***primary receiver***
  - ***5*** differential RF inputs 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/

- The *power consumption* optimization of *4G transceiver* is the key concern.

4G Front End Module Challenges



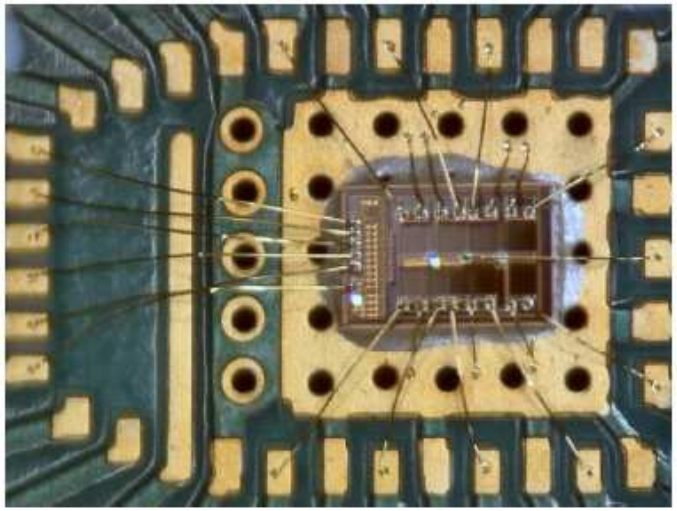
Board photo from http://www.ubmtechinsights.com/

*: estimation, may change according to situation

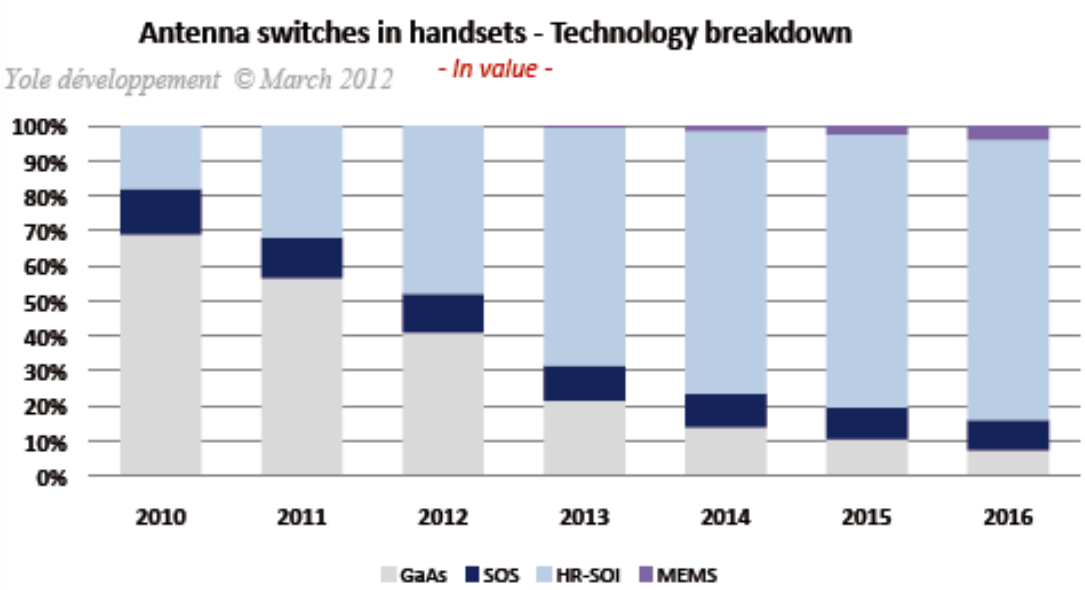
- Most of the *cost* and *complexity* of the cellular *RF ICs* are *in the FEMs* (*~80%* of the cellular *RF BOM*), the *level* of *integration* of *FEM* has *to be improved*.

Low Cost CMOS SOI FEM

- The development of *cost effective FEM in CMOS* has been a *hot topic* during the past years.
- *CMOS SOI technology* has emerged as a *key enabler*. *Antenna switch* integration on CMOS SOI was the first step and was *driven by cost* reduction.
- *CMOS SOI technology* has paved the way for *more integrated FEM* on silicon.



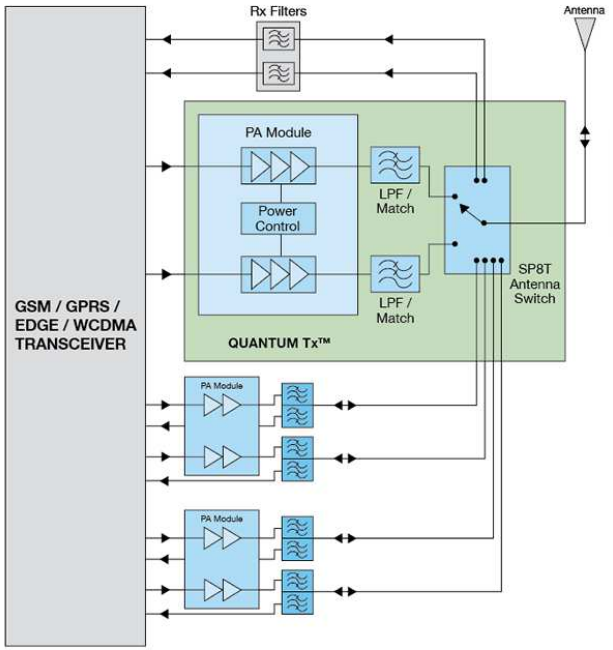
"Cellular antenna switches for multimode applications based on a Silicon-on-Insulator technology", A. Tombak et al., Radio Frequency Integrated Circuits Symposium (RFIC), 2010 IEEE, Page(s): 271 - 274



Architecture Simplification: Converged PA

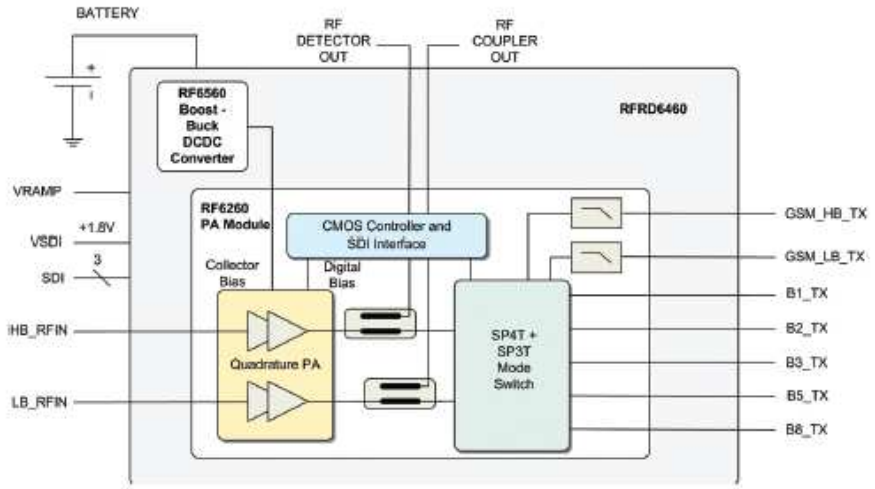
- *4G system architecture* is also *evolving* in order to *enable* more *integration*:

Single band PAs approach:



Source: http://www.triquint.com

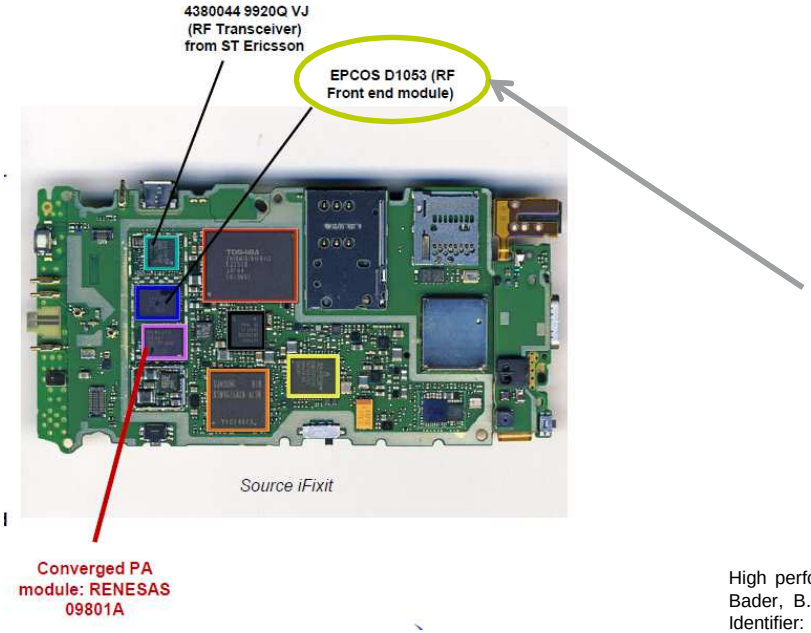
Converged PAs approach:

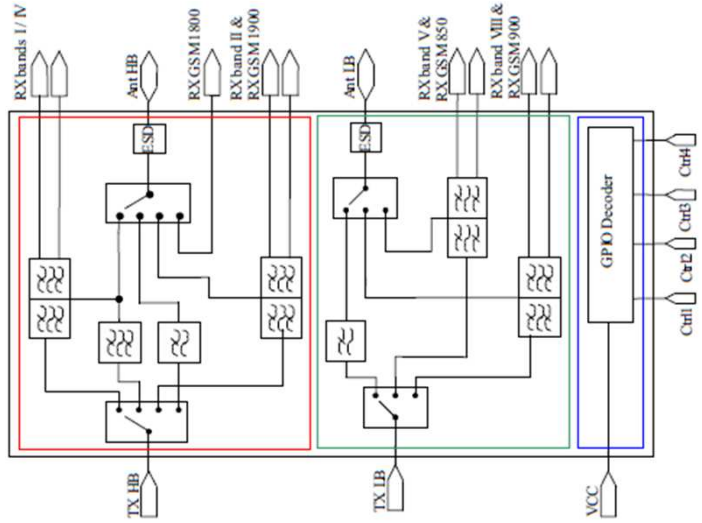


Source: http://www.rfmd.com

4G Duplexer Challenge

- With the adoption of *converged PA*, the *pressure* is now on the *multimode duplexer module* since we have to add a *new duplexer* for each *new band*.





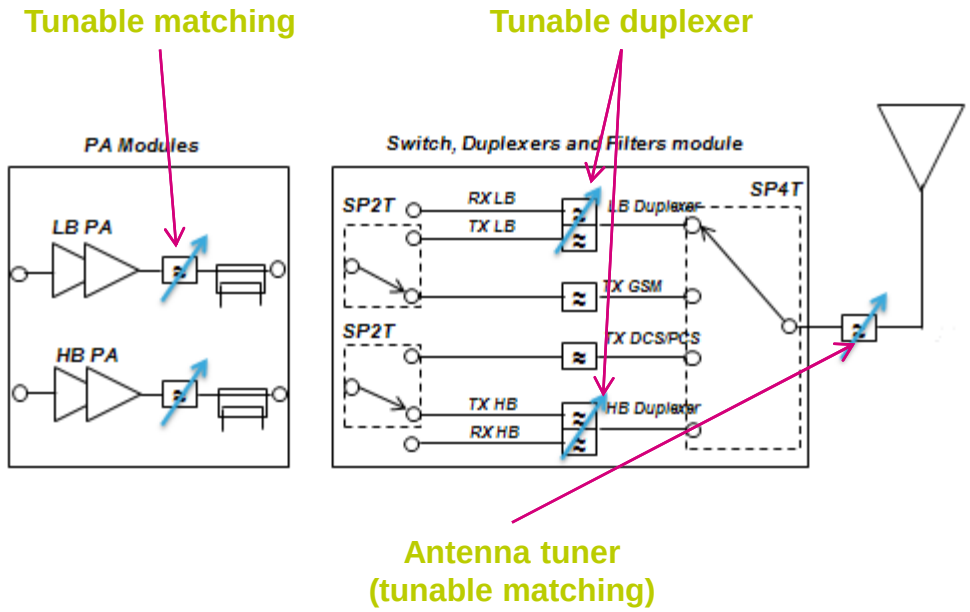
High performance microwave acoustic components for mobile radios Pitschi, F.M.; Kiwitt, J.E.; Koch, R.D.; Bader, B.; Wagner, K.; Weigel, R.; Ultrasonics Symposium (IUS), 2009 IEEE International Digital Object Identifier: 10.1109/ULTSYM.2009.5441550 Publication Year: 2009 , Page(s): 1 - 10

- For only *5 WCDMA bands* we have to deal with a *9 mm x 6 mm x 1.2 mm duplexer module,* moving to *4G* (15 bands) this solution does *not* seem *reasonable*.

Tunable FEM: Holy Grail for Low Cost 4G

- In order to enable a *4G world phone* with a single RF BOM *tunability is now highly desirable* everywhere in the FEM:

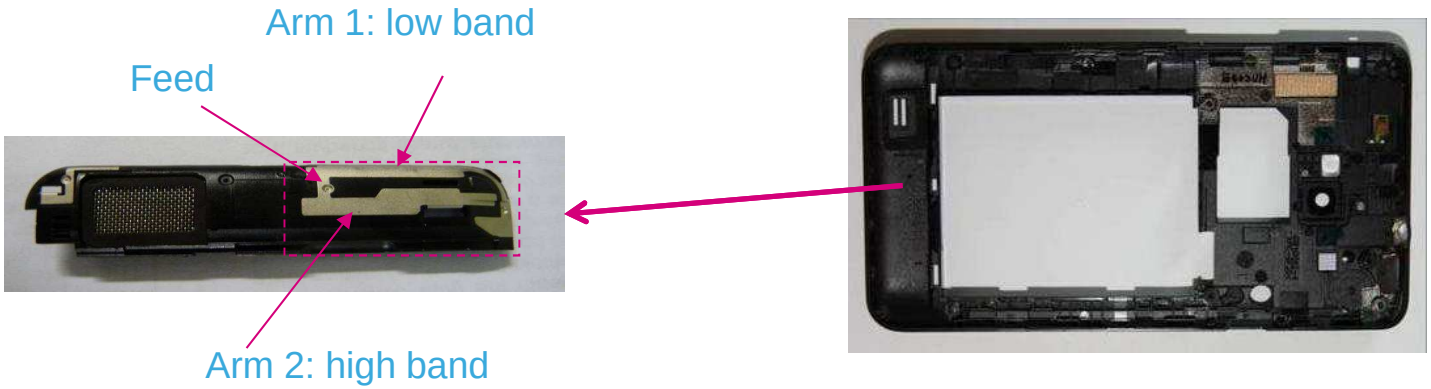
4G Tunable FEM Architecture:



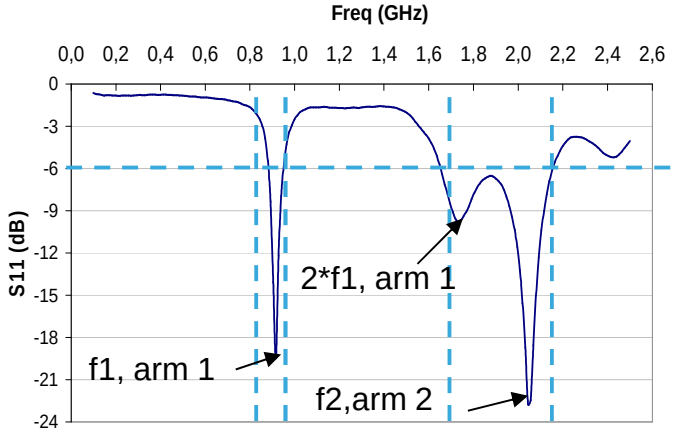
- So far we discuss a lot about ICs, but *what about 4G antennas challenges* ?

Commercial 3G Antennas

- Most *commercial phones (3G)* use a single feed *LDS penta-band antenna*:



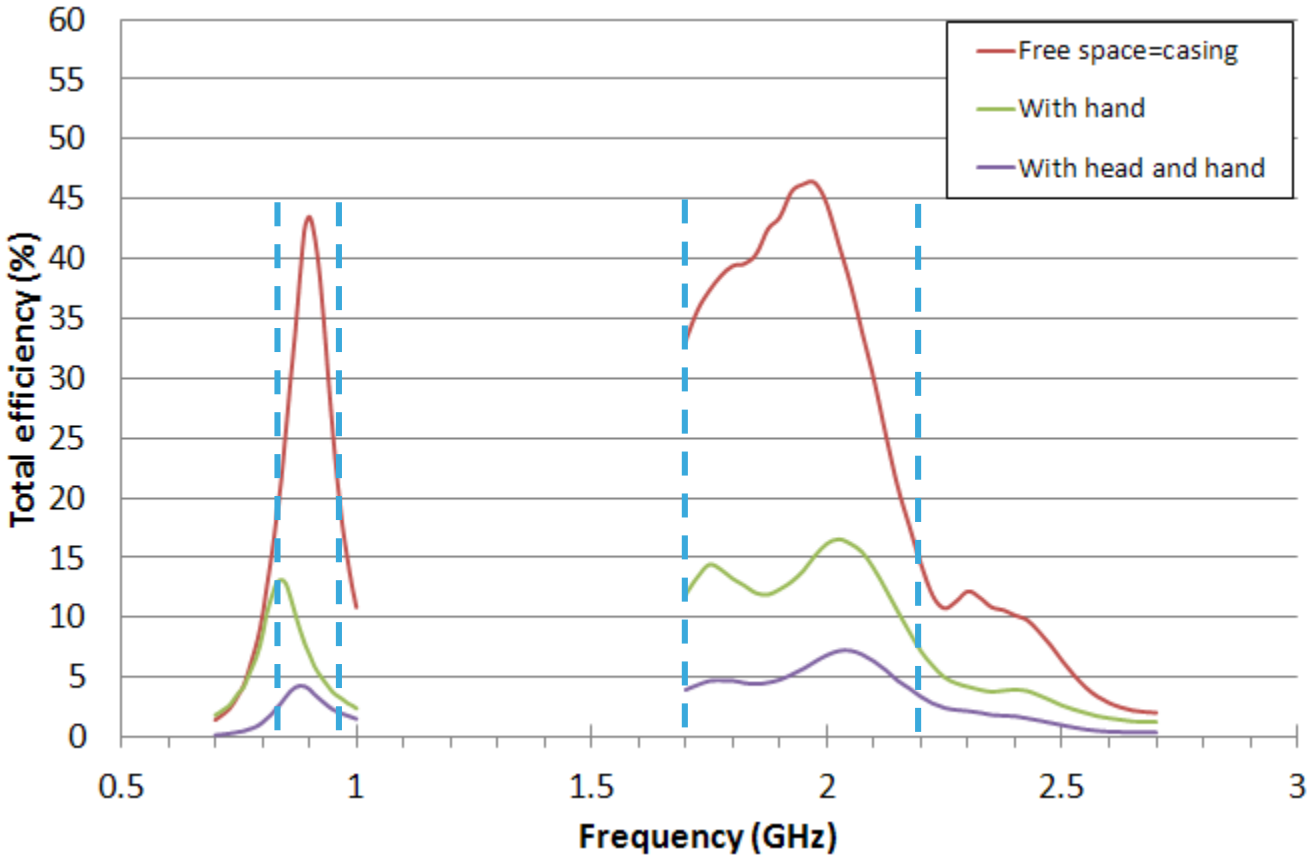
- Those antennas operate on *824-960 MHz* and *1710-2170 MHz* frequency bands:



3G bands

Commercial 3G Antennas Performances

- Using *CTIA OTA configurations*, the efficiency of a *commercial 4.3" 3G smartphone antenna* has been measured (underlining some perspectives):

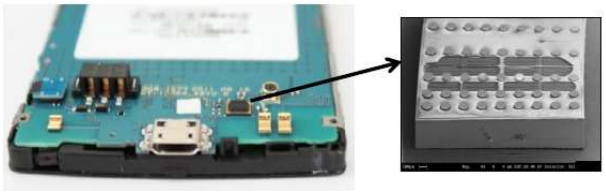


3G Antennas Limitations

- *Current antenna* solution are *not addressing* the *multi bands challenge* of 4G.
- Moreover, after Apple 'Antennagate' crisis *antenna detuning* due to *user interaction* has been a hot topic:

- *Antenna tuner* has then been introduced to solve current antenna issues:

Wispry RF MEMS antenna tuner in Samsung Focus Flash and die SEM view



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

RFMD RF1102 Antenna Tuning Module use in Apple iPhone 5

By courtesy Chipworks

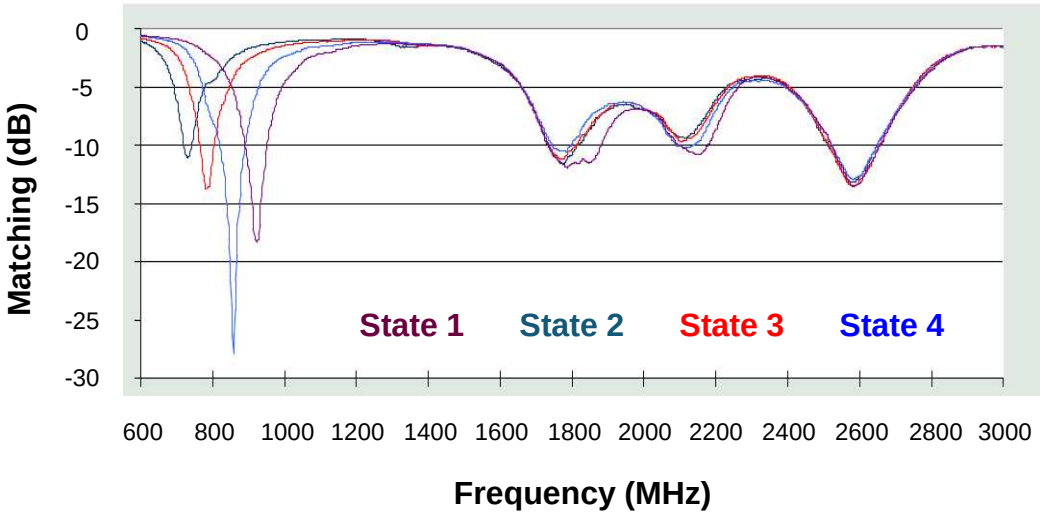
life.augmented

Antenna Tuner Performances

- Unfortunately, from *OTA performances* point of view the *improvement* bring by *antenna tuner* is *not obvious* to demonstrate (*~1.5 dB* extra *TRP*).

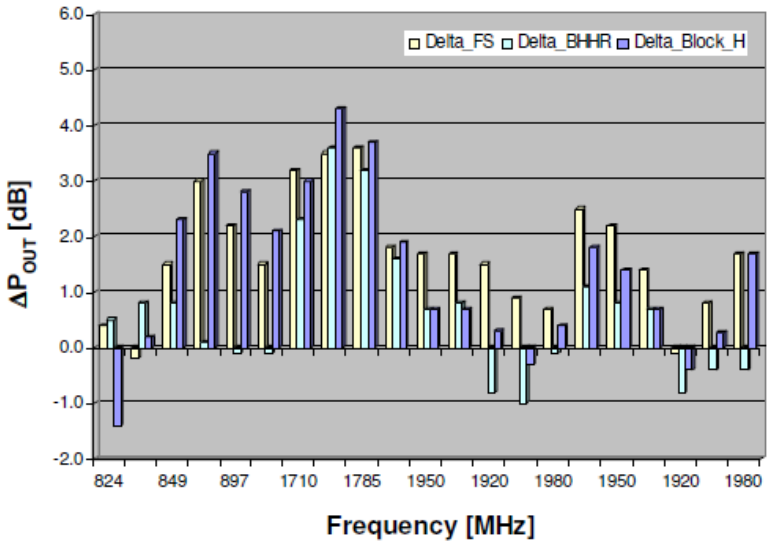
- In fact, antenna tuner is generally used to achieve a *tunable narrow band antenna* in order *to achieve wide band operation < 1 GHz*.

Tunable antenna using a tuner:



Pulse Electronics Adjustable LTE antenna (www.pulseelectronics.com)

TRP improvement thanks to tuner:



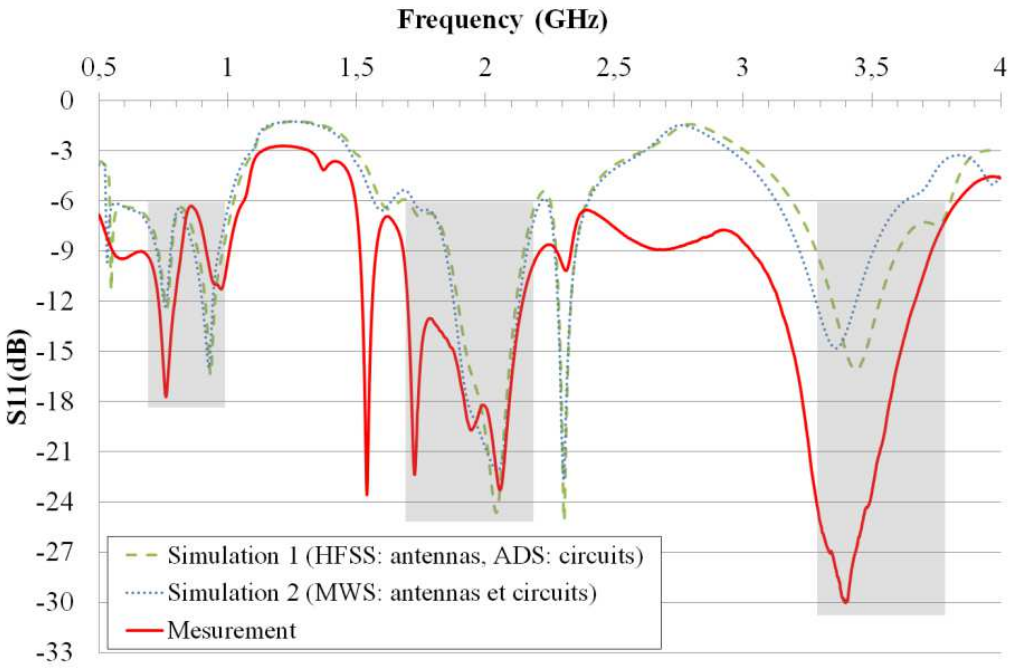
A. Van Bezooijen, "Antenna Tuner for Hand-sets", WSO: Advancements in Front End Modules for Mobile and Wireless Applications, RFIC/IMS2012, Montreal, June 17-22, 2012 23

4G Antenna Challenge

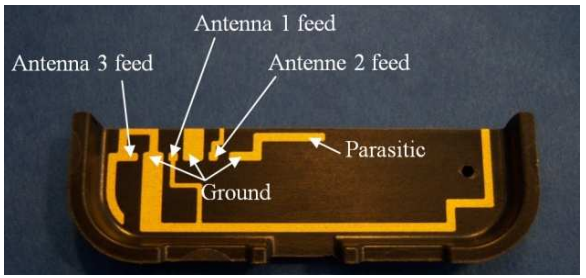
- Antenna tuner is definitively the right solution in order to address today wireless system challenges, but moving to 4G we will have to deal with:
  - Intraband carrier aggregation (< 1 GHz we need a real wideband antenna)
  - User interaction impact has to be minimized on wide bands (especially < 1 GHz)
  - 2.5 – 2.7 GHz band support for FDD LTE
  - 3.4 – 3.8 GHz band support for TDD LTE
- Combining antenna and circuit design techniques can we imagine an innovative antenna solution able to offer the following features:
  - Wideband operation (from 700 MHz to 3.8 GHz)
  - Single feed
  - Resilient to user interaction (always limiting mismatch loss with FEM on all bands)
  - Generic (customizable by modifying the circuit instead of the radiating elements)

Innovative 4G LDS Antenna

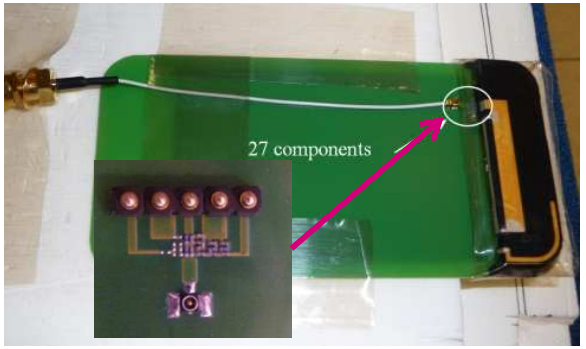
- Let's try something an antenna designer will not do: use *several IFAs* and *add some circuit* design techniques *to achieve a wide band single feed antenna*:



Antenna Bottom view



PCB view

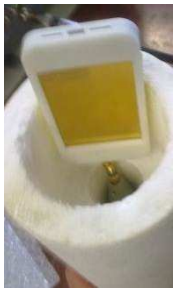


- All the *technical details* will be discussed during *Florence Sonnerat's talk* on Thursday *April 11th* during session *CA11 (Small antennas and matching circuits 1).*

4G Antenna Resilient to User Interaction

- Using CTIA OTA configurations, this *antenna design* has demonstrated to be *robust to user interaction* (in terms of matching):

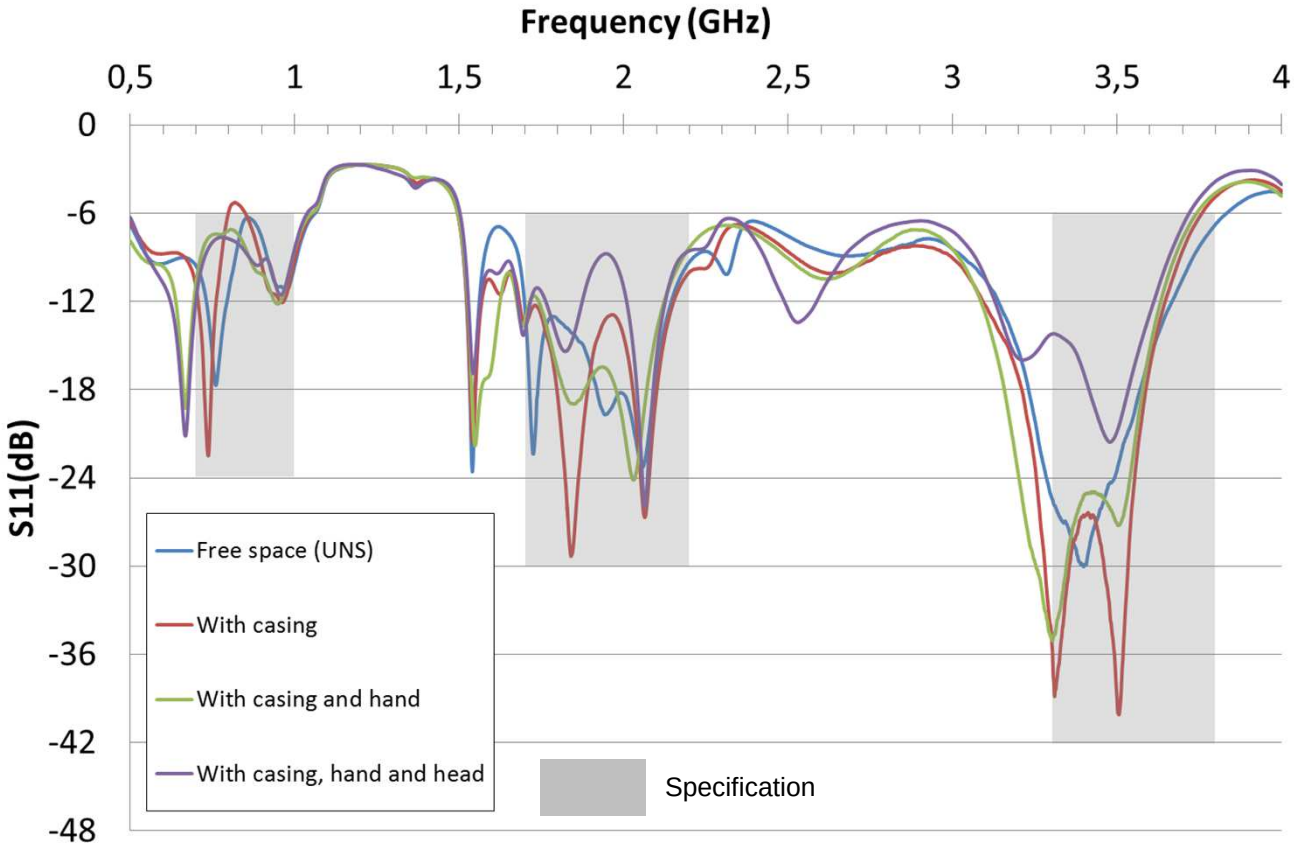
Without casing



With casing

With casing and hand

With casing, hand and head

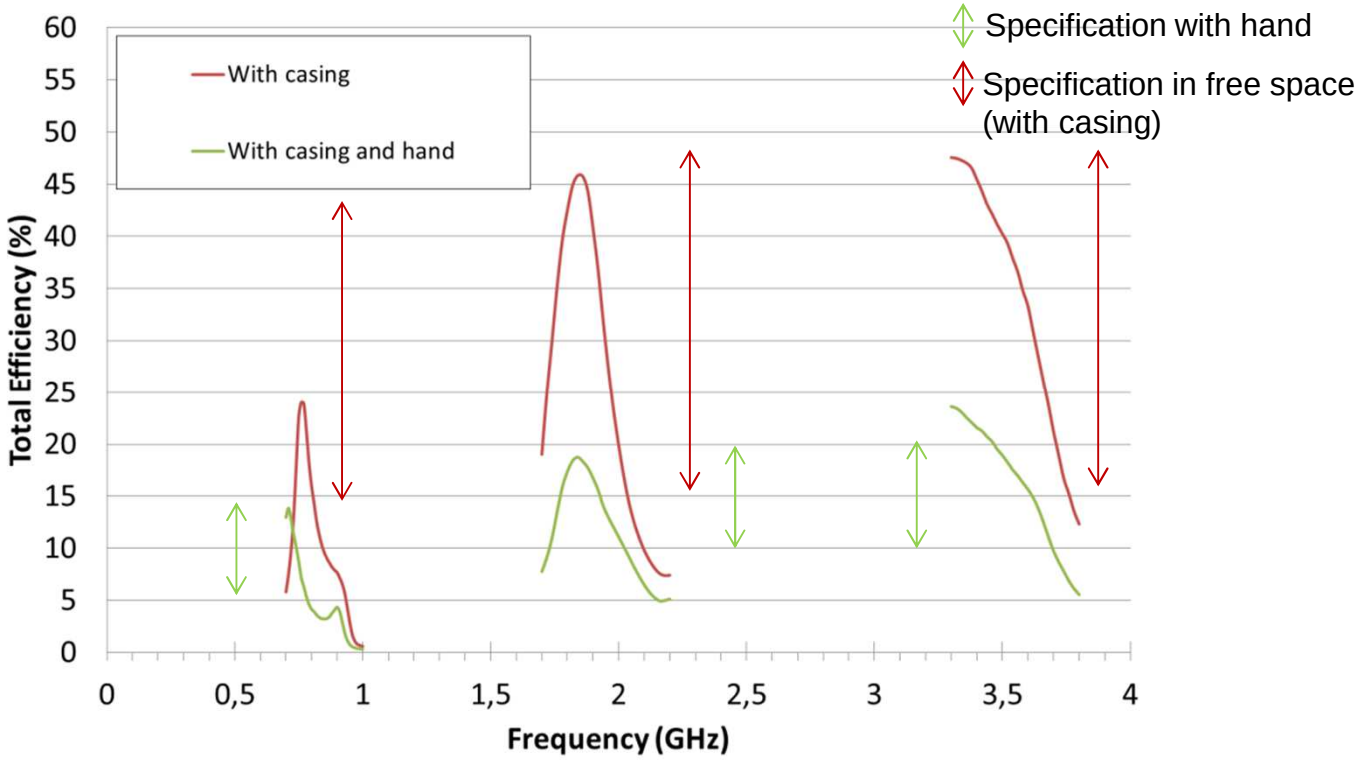


Innovative 4G LDS Antenna Performances

- Some *efficiency measurement* have been performed exhibiting *promising performances*:

Free space (with casing)

With casing and hand

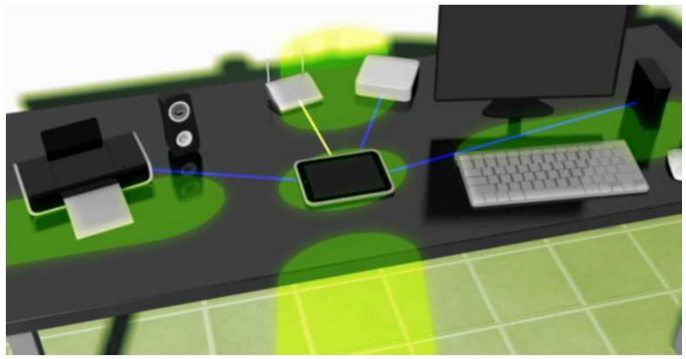


- Keeping in mind that it is a *first prototype*, we have some *margin* here to develop *innovative and high performances antenna* designs *using* proposed *concept*.

60 GHz Technology Context

- Since *data consumption* is going *higher* and higher, short distance (< 3m) *high speed wireless* solution is a *key differentiator* (cable replacement):

Short distance ad hoc link:



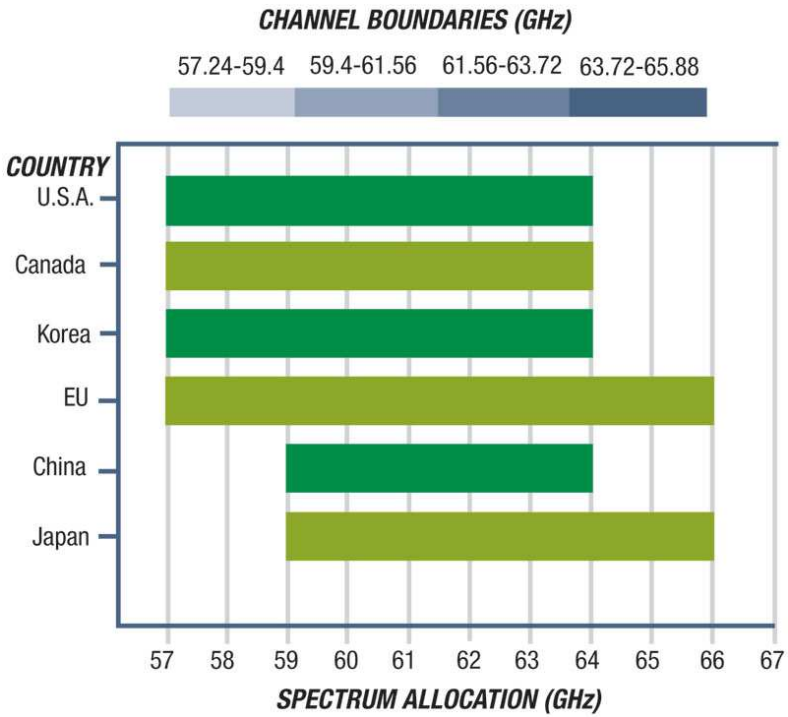
http://www.theverge.com/2013/1/14/3875308/wigig-gets-official-standards-for-short-range-high-speed-wireless

Cloud based Sync. & delivery services:

- *User experience improvement* is obvious and *high speed 60 GHz wireless solution* can address *countless applications*.

60 GHz / WiGig Technology Overview

- Leveraging the *wide free spectrum available* worldwide at *60 GHz*, data rates up to *7 Gb/s* can be achieved (WiGig standard).



http://www.rtcmagazine.com/articles/view/102301

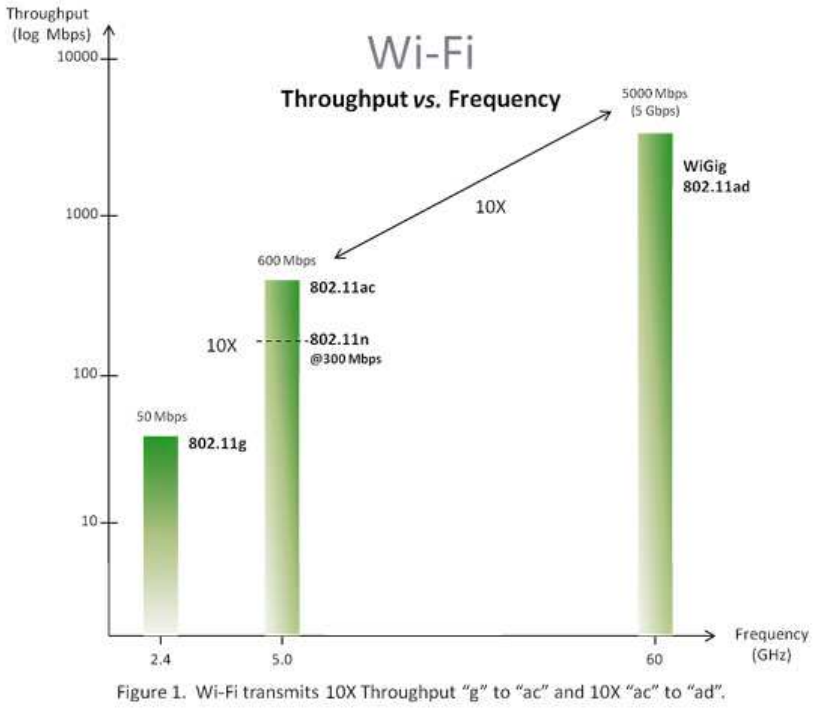


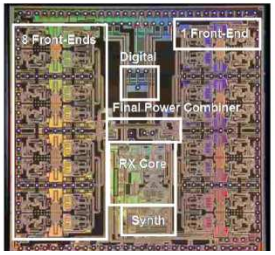
Figure 1. Wi-Fi transmits 10X Throughput "g" to "ac" and 10X "ac" to "ad".

http://www.theverge.com/2013/1/14/3875308/wigig-gets-official-standards-for-short-range-high-speed-wireless

CMOS / BiCMOS 60 GHz ICs

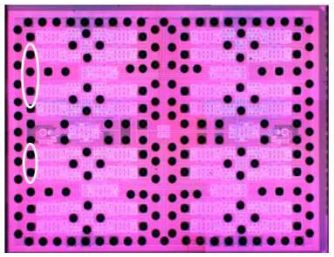
- Several 60 GHz chipset solutions have been developed, highlighting *silicon* as the *technology* of choice to address *60 GHz applications:*

IBM / Mediatek



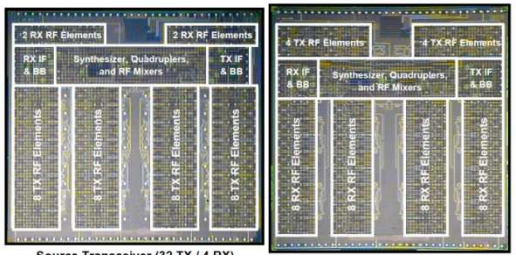
A. Valdes-Garcia et Al., "A SiGe BiCMOS 16-Element Phased-Array Transmitter for 60GHz Communications", IEEE ISSCC 2010

Intel



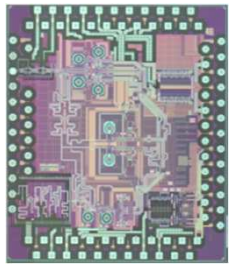
E Cohen et Al., "A thirty two element phased-array transceiver at 60GHz with RF-IF conversion block in 90nm flip chip CMOS process", IEEE RFIC 2010

SiBeam



S. Emami : "A 60GHz CMOS Phased-Array Transceiver Pair for Multi-Gb/s Wireless Communications ", IEEE ISSCC 2011

ST

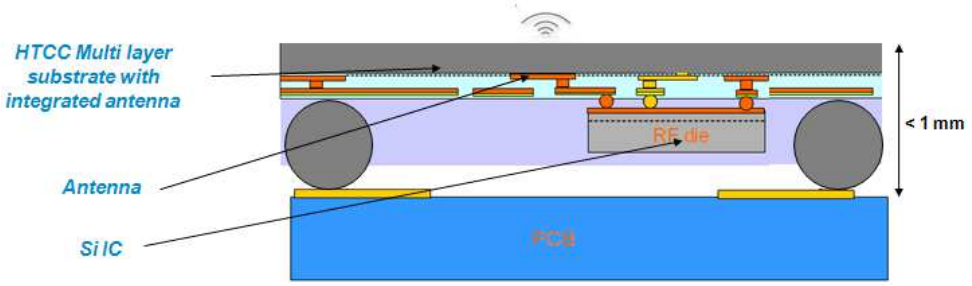


A. Silligaris, "A 65nm CMOS Fully Integrated Transceiver Module for 60GHz Wireless HD Applications ", IEEE ISSCC 2011

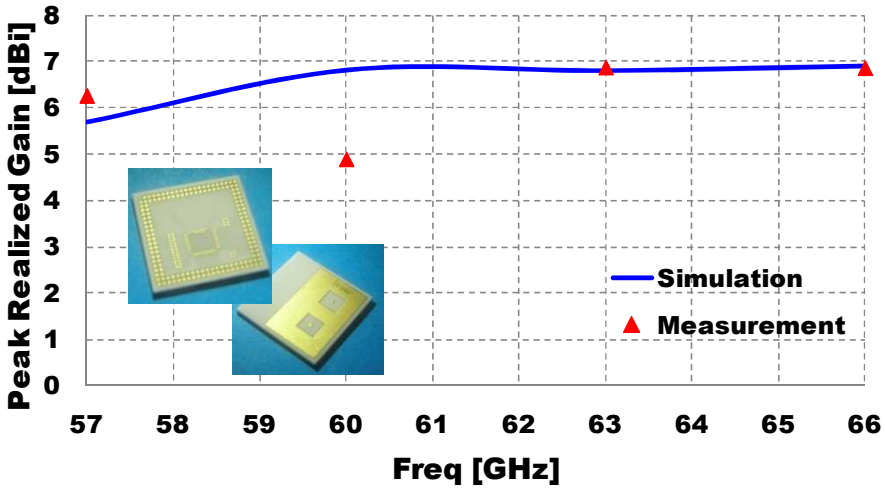
- The *main challenge* now concerns the development of *low cost 60 GHz packaging technology* cleverly combining:
  - Antenna In Package achieving acceptable performances
  - Low loss and low cost substrate technology
  - Compliant with industrial assembly constraints (to enable volume production)

60 GHz Antenna In Package

- *First 60 GHz modules* have been manufactured using *HTCC/LTCC* technologies.
- *Antenna in Package approach* has been used in order to *minimize* the interconnection *loss* at 60 GHz and offer a *cost effective* solution.



Sources: STMicroelectronics



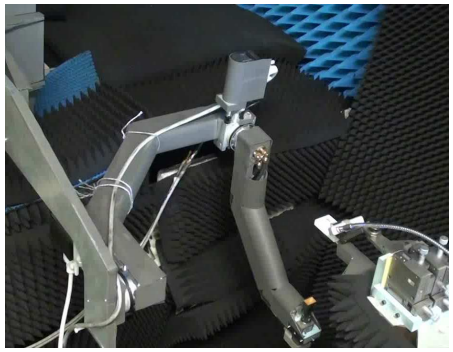
R. Pilard, " Industrial HTCC SiP solution for 60 GHz applications", IEEE RFIC 2012

- Antenna measurement has been performed at module level and exhibit *appealing performances* (antenna *gain ~5.8 dBi* @ 57 GHz).

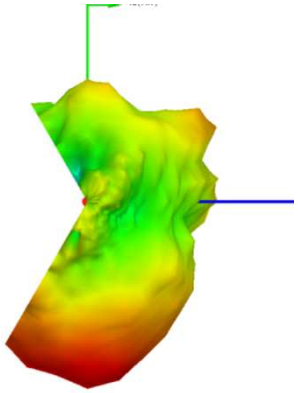
60 GHz Antenna Measurement

- Radiation pattern *measurement* of *60 GHz antenna* is also a *challenge*:

3D Radiation Pattern measurement

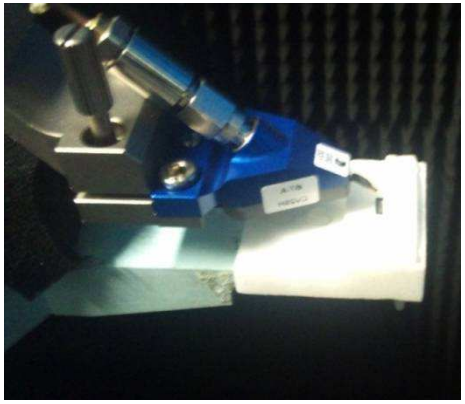


Sources: UNS/EPIB

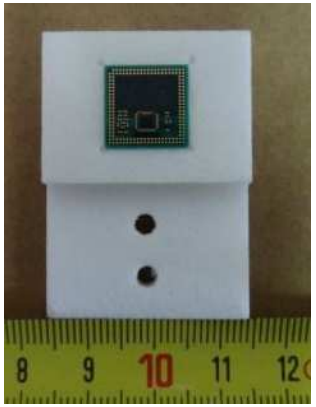


R. Pilard, "HDI Organic Technology Integrating Built-In Antennas Dedicated to 60 GHz SiP Solution", IEEE AP-S 2012

RF Probing Constraints



Sources: UNS/EPIB



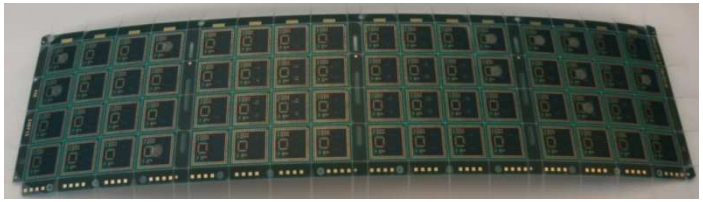
Sources: STMicroelectronics

- A very good example of *cross cultural development* leveraging *antenna* and *circuit* communities *expertise*.

Low Cost 60 GHz Packaging Technology

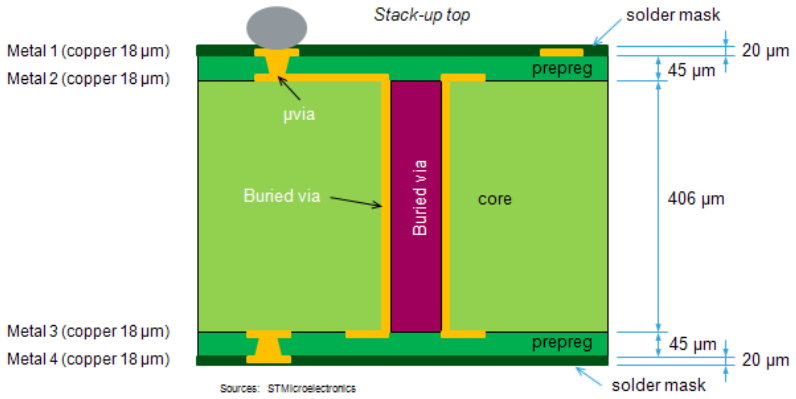
- Unfortunately, *HTCC/LTCC* technologies face some *limitations*:
  - *High cost* (in comparison with standard IC package)
  - *Automated assembly* is an *issue* (for semiconductor player)
- *ST* has developed a *low cost* organic *mmW HDI* packaging *technology* :

60 GHz module in strip format:



Sources: STMicroelectronics

1+2+1 mmW HDI Technology:



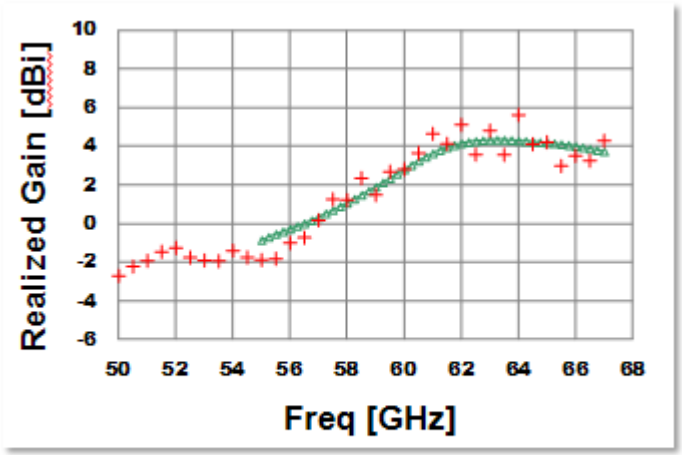
R. Pilard, "HDI Organic Technology Integrating Built-In Antennas Dedicated to 60 GHz SiP Solution", IEEE AP-S 2012

Low Cost 60 GHz Antenna Performances

- The selection of low *loss material* was the *key challenge*.
- A *first prototype* has been demonstrated in 2012 exhibiting *antenna performances competing with HTCC/LTCC* :

60 GHz antenna performances achieved in mmW HDI organic technology:

Measured realized gain:

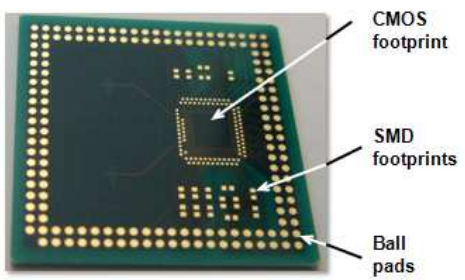


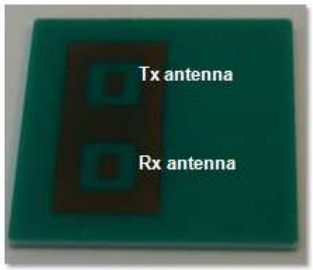
Sources: STMicroelectronics

60 GHz mmW HDI organic package with integrated antennas:

Top side:

Bottom side:

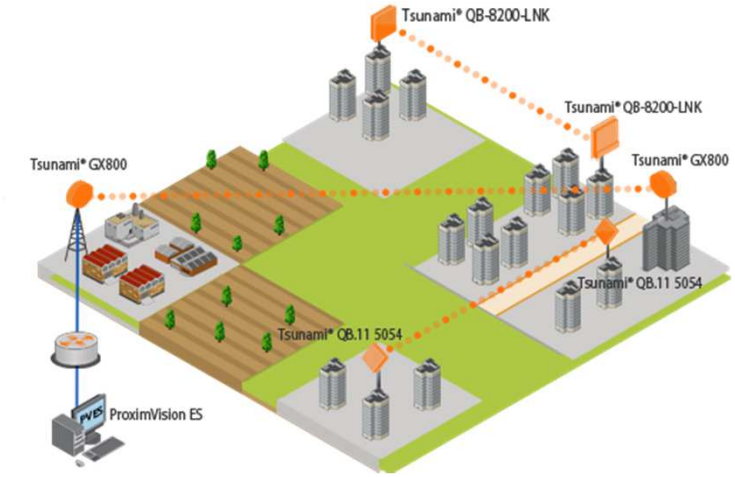




R. Pilard, "HDI Organic Technology Integrating Built-In Antennas Dedicated to 60 GHz SiP Solution", IEEE AP-S 2012

4G Small Cell and Wireless Backhaul Challenge

- *4G* will offer *data rates* up to 10/100 Mbps to handset, which puts a lot of *pressure* on the 4G *networks*.
- *Small cells* will play a key role here in order to *increase the network capacity*.
- Backhaul connection is an issue since civil works cost can limit the deployment of small cells: *wireless backhaul* is here *mandatory*.



- Since *high data rates* (1 Gb/s in full duplex) are required *at low cost*, *60 GHz* & *70-80 GHz* wireless backhaul solutions are *considered*.

60 GHz Backhaul Motivation

- There is currently an *opportunity* to *leverage* our ongoing *CMOS 60 GHz chipset* development in order *to address* the *4G small cell wireless backhaul*:
  - **Licensing costs**:

    Regulators are allocating the *60 GHz spectrum* on a *license free* or *light licensing* basis
  - **Spectrum availability**:

    7 GHz of bandwidth available worldwide enable *simple modulation* to achieve *high data rate*
  - **Frequency re-use**:

    Thanks to *oxygen absorption @ 60 GHz* and related short distance link
  - **60 GHz backhaul already in use**:

    Orange Austria is using 90 wireless *backhaul bridges* working *at 60 GHz* (in LOS configuration) to support an *LTE metrocell in Vienna* (via a partnership with Alcatel-Lucent)

Existing 60 GHz Wireless Backhaul solution

- Some *60 GHz wireless backhaul solutions* are *already available on the market*.

Siklu

ETHERHAUL-600

Sub10

LIBERATOR-V320

Ericsson

MINI-LINK PT3060

Bridgewave

AR60

Ceragon

FibeAir-10060

Proxim

Tsunami® QB-62000

- But *price point remains high* (~20 k$), this is *where WiGig can play a role*.

Backhaul Business Opportunity for WiGig Chipset Manufacturers

- *Leveraging WiGig* chipsets, *low cost 60 GHz backhaul* solution is not so far away:

Existing 60 GHz Backhaul Systems :

- Max Output power (at antenna port): *~10 dBm*
- Modulation scheme /sensitivity:
  - *QPSK* / *-62 dBm*
- Antenna Gain: ***~38 dBi***
- Data rates:
  - *100 Mbps*
  - 300 Mbps
  - *1000 Mbps*
- Range: from *500 m* up to *1.5 km*
- Duplex mode: TDD & FDD

WiGig 60 GHz Systems :

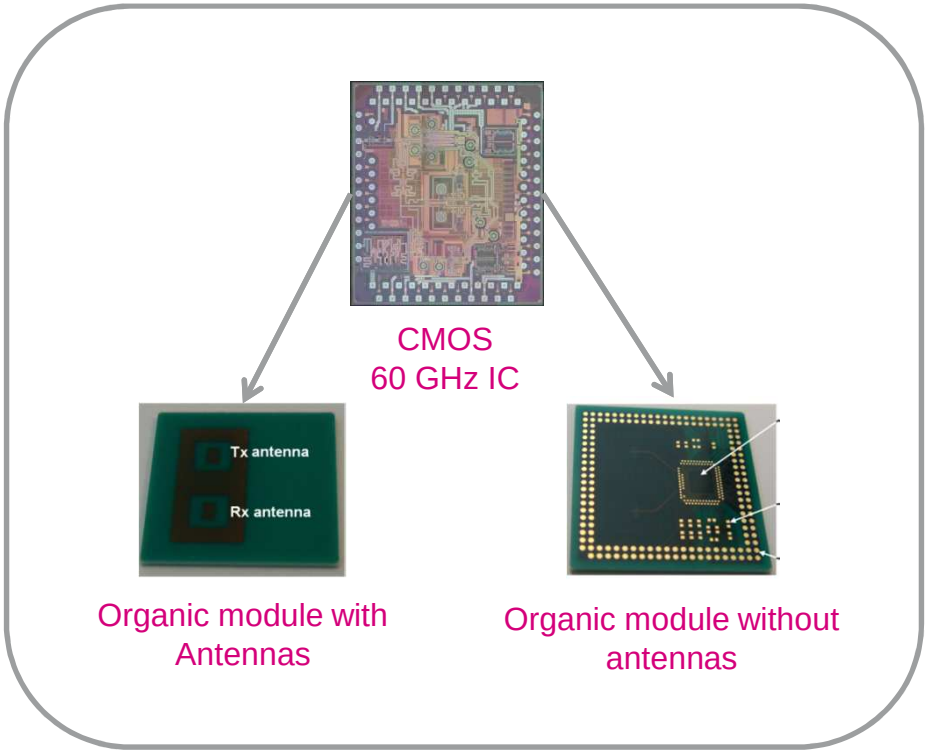
- Max Output power (at antenna port): *~10 dBm*
- Modulation scheme /sensitivity:
  - ∏/2 *BPSK* (MCS-1) / *-68 dBm*
  - ∏/2 BPSK (MCS-5) / -62 dBm
  - ∏/2 QPSK (MCS-6) / -63 dBm
  - ∏/2 *QPSK* (MCS-9) / *-59 dBm*
- Antenna Gain: ***~5 dBi***
- Data rates:
  - *385 Mbps* (MCS-1, single carrier)
  - 1251.25 Mbps (MCS-5 , single carrier)
  - 1540 Mbps (MCS-6, single carrier)
  - 2502.5 Mbps (MCS-9, single carrier)
- Range: from *1 m* up to *10 m*
- Duplex mode: TDD

- It seems to be *all about antennas* performances.

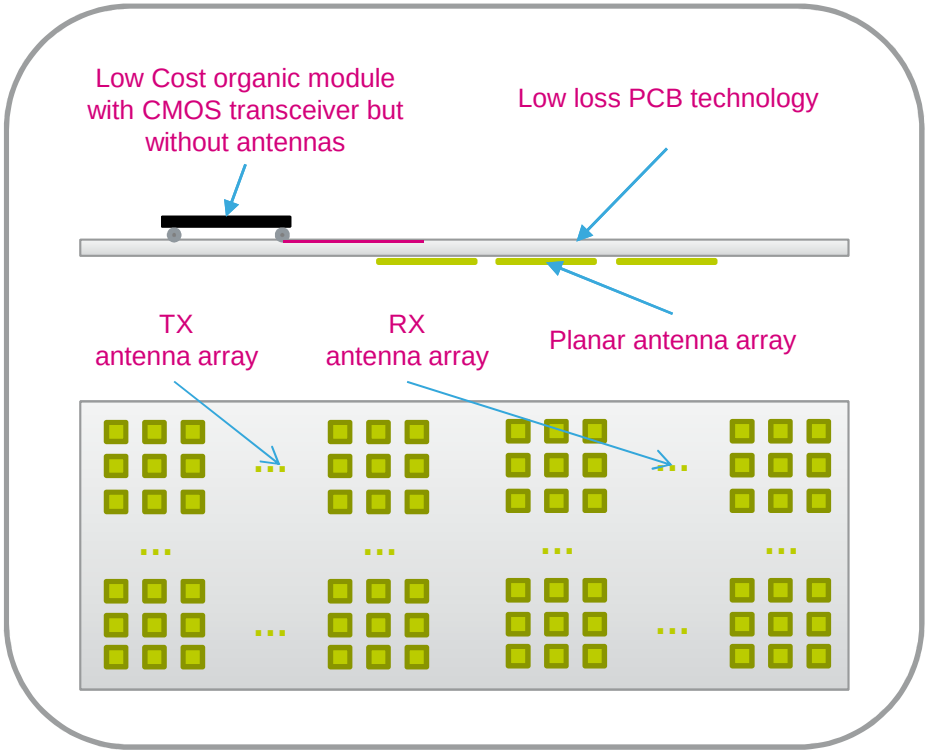
60 GHz Antenna as a Business Enabler

- *Leveraging* their *60 GHz expertise*, semiconductor player involved in WiGig technology development can offer *added value* on *two key points*:

1 CMOS IC serving different applications through packaging customization:



Low Cost 60 GHz Antenna Array:



Conclusion & Perspectives

- The *main challenges* faced by current *wireless systems* are *involving* the antenna in a way or in an other:
  - The *challenge* to support *4G bands* is not limited to the RFIC alone
  - At *60 GHz*, *low cost antenna* development has proven to be a *key enabler*
- We are reaching the *limit* of *incremental innovation*, we have to *think out of the box*:

  “If you always do what you always did, you will always get what you always got”

  Albert Einstein
- To do so, *antenna* and *circuit* community have to exchange more. *Cross cultural* developments are now *mandatory* to deliver *disruptive innovation*.
- We manage to have the digital and RF/Analog designers understand each other, it should not be this hard to *bridge the gap between antenna and circuit communities* (at least it is worth trying).

Thank you for you attention!

frederic.gianesello@st.com