A Framework for Coherent Functional Description and Hardware Abstraction in RF Front Ends

By:

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Goals

- Presentation of the hardware abstraction interest in RF front-ends
- Presentation of the proposed hardware abstraction approach in RF front-ends
- Presentation of a RF design framework based on hardware abstraction concepts

Outline

- Motivations
- Hardware abstraction definition
- Hardware abstraction in RF front-ends
- Existent approaches
- Our hardware abstraction framework
- Conclusion

Motivations

- Tremendous wireless networks evolution
- Multiple communication services
- Software defined radio concept
  - Awareness, reconfigurability, interoperability
- Need for codesign for more optimal performance
- Wireless market growth:
  - Customized products
  - Time-to-market reduction
  - Cost reduction
  - Reliable and low consumption handheld terminals

The Dilemma

- Such ambitious objectives need:
  - An adaptive design flow
  - A fully automatic (or semi-automatic) design and synthesis processes
  - A high-level description of systems and subsystems
- Then, hardware abstraction becomes interesting and more, essential !

Hardware Abstraction (1/2)

Definition:

Hardware abstraction (HA) is a method of masking physical details of hardware, allowing the designer to focus on the effects rather than the details resulting of manipulating directly the hardware. It is a way to describe the functionality without handling the intrinsic architecture of communication equipments [1, 2, 3].

[1] Sungjoo Y., and Jerraya A.A,"Introduction to hardware abstraction layers for SoC", Design, Automation and Test Conference 2003, 2003, pp. 336 – 337.

[2] http://en.wikipedia.org/wiki/Abstraction_layer

[3] http://en.wikipedia.org/wiki/Hardware_abstraction_layer

Hardware Abstraction (2/2)

HA advantages and provision:

- RF front-end (RFFE) HA is based up on a functional description which offers:
  - A compact way to describe the overall system
  - Hiding subsystems and physical details
  - Facilitating high-level simulation
  - Making design process more reliable and almost fully automatic

Existent Approaches (1/6)

- **In baseband side:**
  - HAL (WWRF & SDRF definition) [4]
  - OMG's UML profile for software radio [5]
- **In RFFE:**
  - OMG's UML profile for software radio [5]

[4] "Hardware abstraction in an end-to-end reconfigurable device", World Wireless Research Forum, 2004, www.e2r.motlabs.com.

[5] "PIM and PSM for software radio components", Object Management Group, 2005.

Existent Approaches (2/6)

OMG's contribution:

- UML profile for software radio aims to enable the development of UML tools to support the development of software radio applications and systems [5]
- OMG has defined a set of UML stereotypes to describe communication equipments
- The UML profile for software radio includes the specification for:
  - Application and device components
  - Communication equipments
  - Infrastructure

[5] "PIM and PSM for software radio components", Object Management Group, pp. 41, 2005.

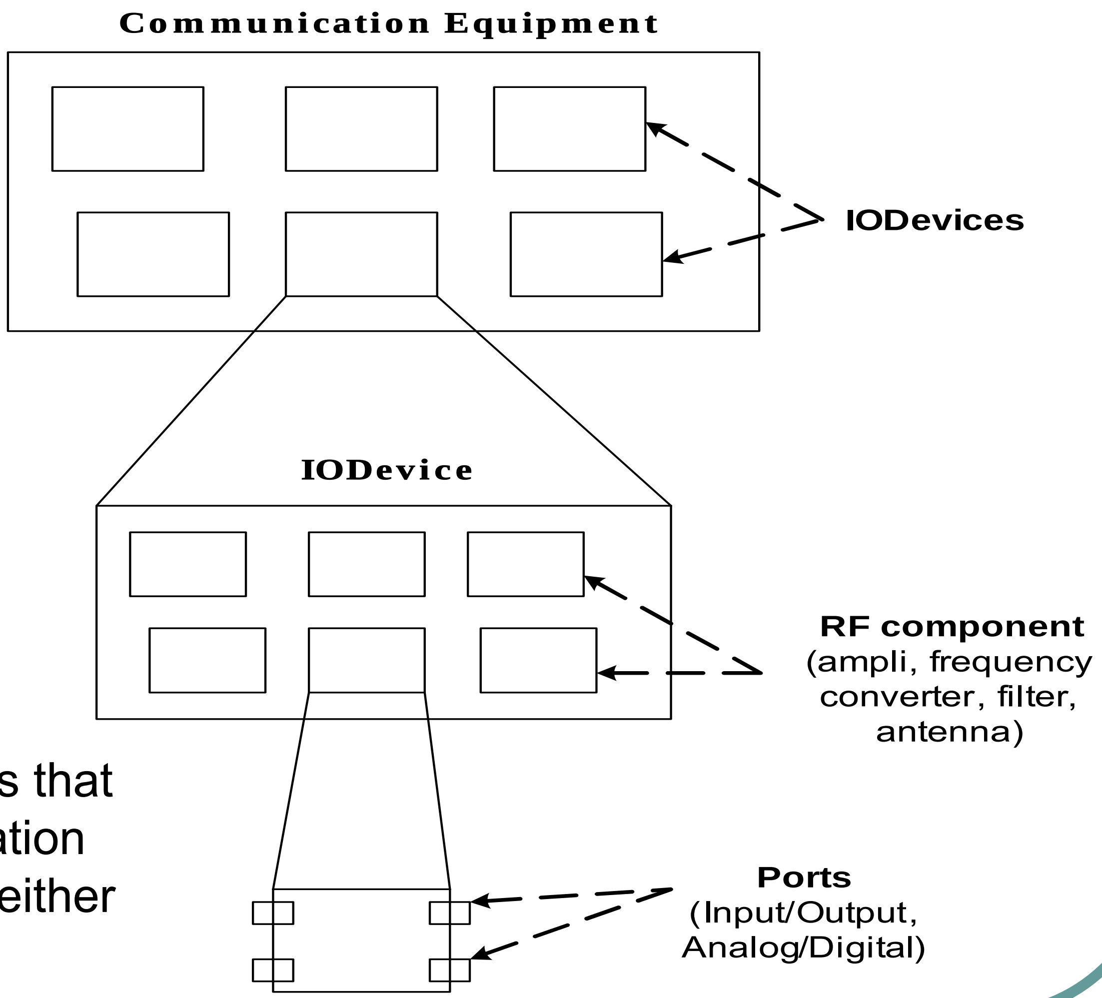
Existent Approaches (3/6)

- Application and Device components package [5]:
  - Defines the basic types, application and device components for software radio
- Communication equipment package [5]:
  - Defines basic RF devices' stereotypes
- Infrastructure package [5]:
  - Defines communication channel, radio services, management and deployment.

[5] "PIM and PSM for software radio components", Object Management Group, pp. 41, 2005.

Existent Approaches (4/6)

Abstraction Hierarchy



Ports are the interfaces that ensure the communication between equipments (either analog or digital)

Existent Approaches (5/6)

Critics:

- Attributes were checked regarding some criteria :

Criteria	**Pass**	**Fail**
Sufficiency	X	
Organization	X	X
Redundancy		X
Completeness (1)		X

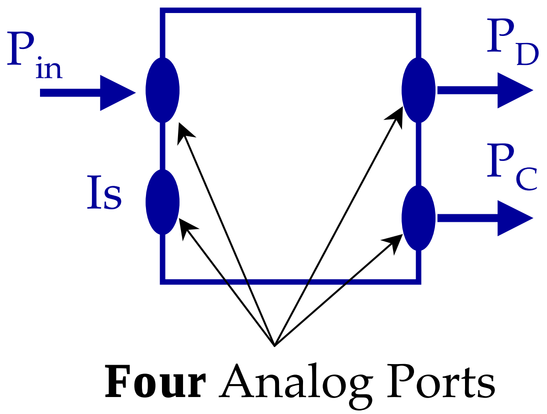
(1) Completeness regarding the number of devices already described (i.e. **coupler**)

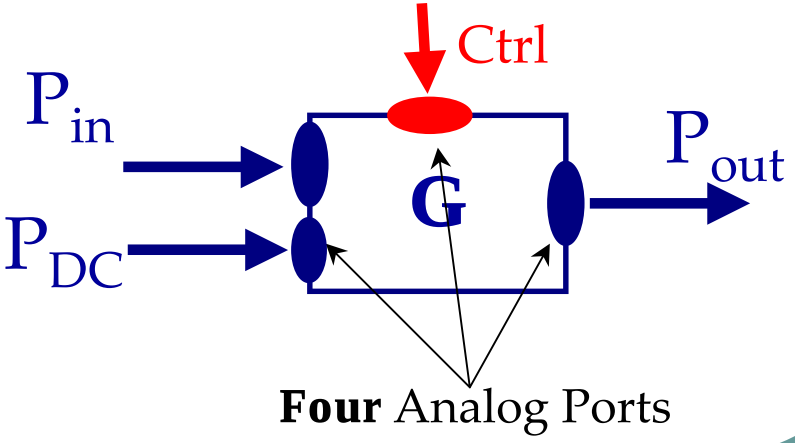
Existent Approaches (6/6)

Some devices are not represented by OMG:

Coupler

AGC





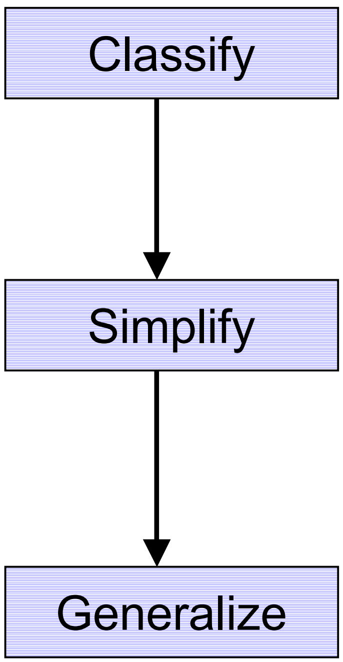
Our HA framework (1/13)

Research Methodology

1. Classify OMG attributes by category
2. Prove their completeness

1. Determine the relationships between them
2. Deduce a minimal set of attributes describing each RF component

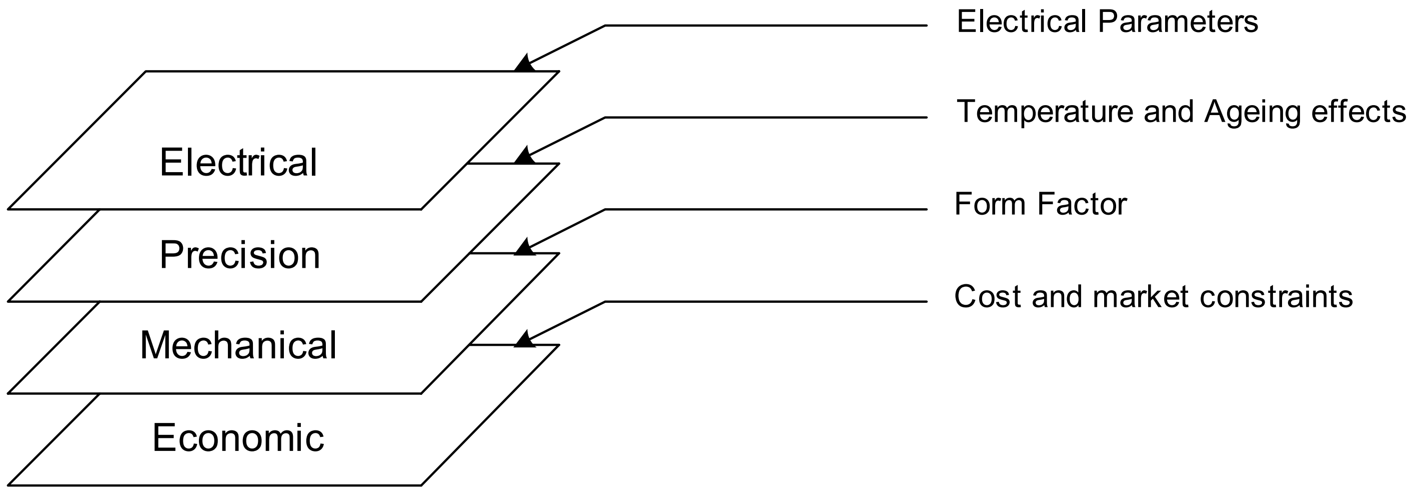
1. Deduce a minimal set of attributes describing all types of RF component
2. Prove its completeness



Our HA framework (2/13)

Classify:

- OMG attributes can be classified into four planes:



Our HA framework (3/13)

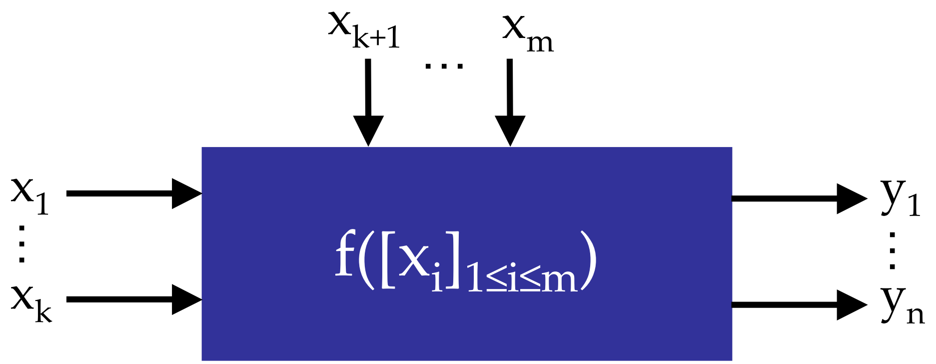
Simplify and Generalize:

- Regarding the OMG contribution, the idea is to:
  1. Figure out a minimal sets of attributes that **FULLY** describes each RF component (Simplify)
  2. Figure out a minimal set of attributes that **FULLY** describes all RF components (Generalize)
- Advantages:
  - Description **Completeness**
  - Description **Genericalness**
  - Description **Efficiency**

Our HA framework (4/13)

Generalize:

- A device is a black box characterized by:
  - A functionality (transfer function)
  - Input / Output / Configuration Parameters



CommEquipment

$[x_i]_{1\leq i\leq k}$: Inputs

$[x_j]_{k+1\leq i\leq m}$: Config. Params

$[y_l]_{1\leq l\leq n}$: Outputs

f(): functionality (transfer function)

Our HA framework (5/13)

- Mathematically speaking,
  - The device functionality can be modeled by a multi-dimensional transfer function *f*
  - Inputs / Outputs / Config. parameters can be modeled by one-dimensional scalar matrices designated resp. $[x_i]$ and $[y_j]$

$$\begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix} = f\left(\begin{bmatrix} x_1 \\ \vdots \\ x_m \end{bmatrix}\right)$$

Our HA framework (6/13)

Hardware Framework Main Objective:

- MAINLY, fully (or at least semi-) automated process of topology choice of any RF system from Functional Description to Synthesis
- However, currently **no** functional description **nor** synthesis steps exist in design cycle !
- Then, How to do?
  - We must adapt the RF design flow by integrating these two steps

Our HA framework (7/13)

Our Proposal:

Specifications

Analysis

Synthesis

Implementation

Validation

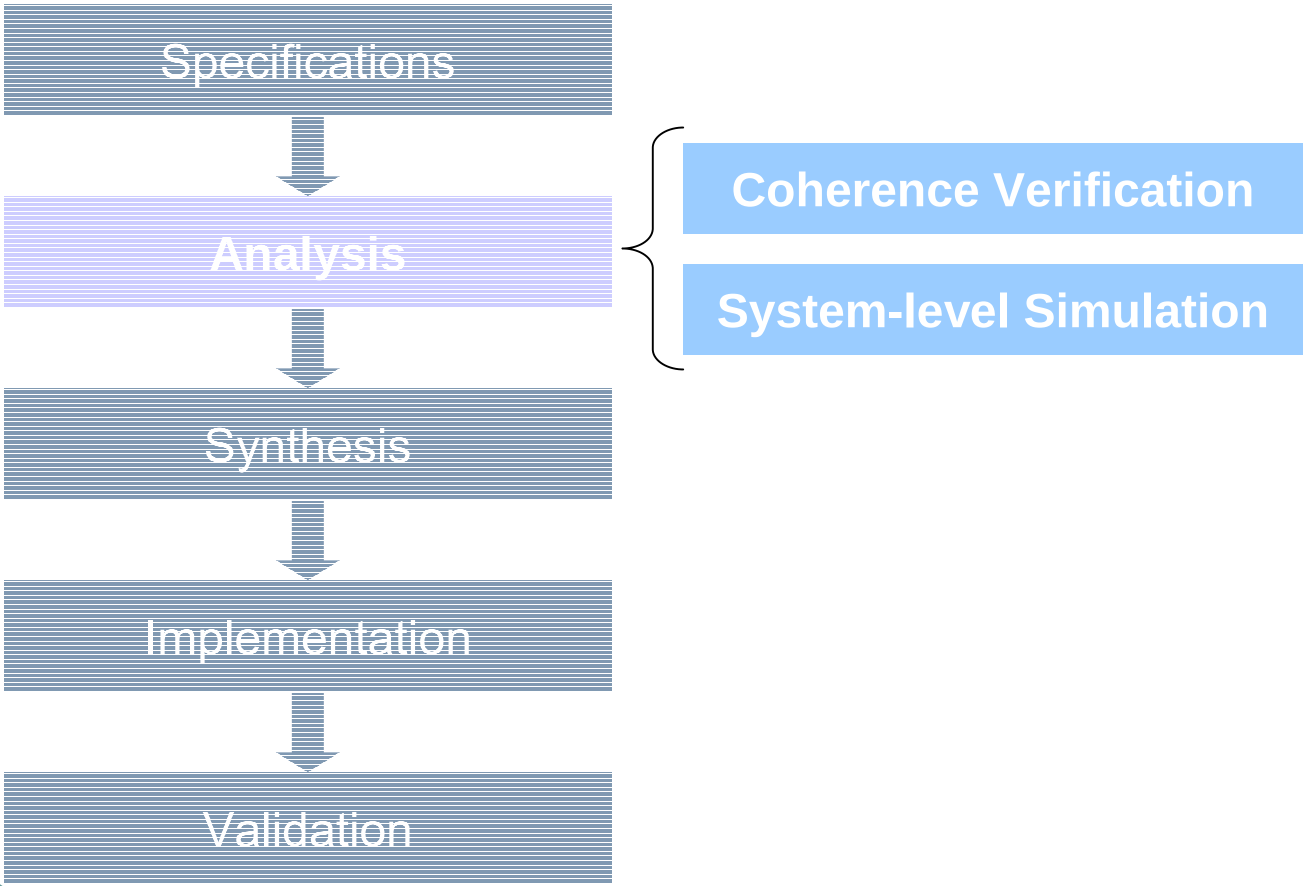
UML Diagrams

XML Description

Functional Description

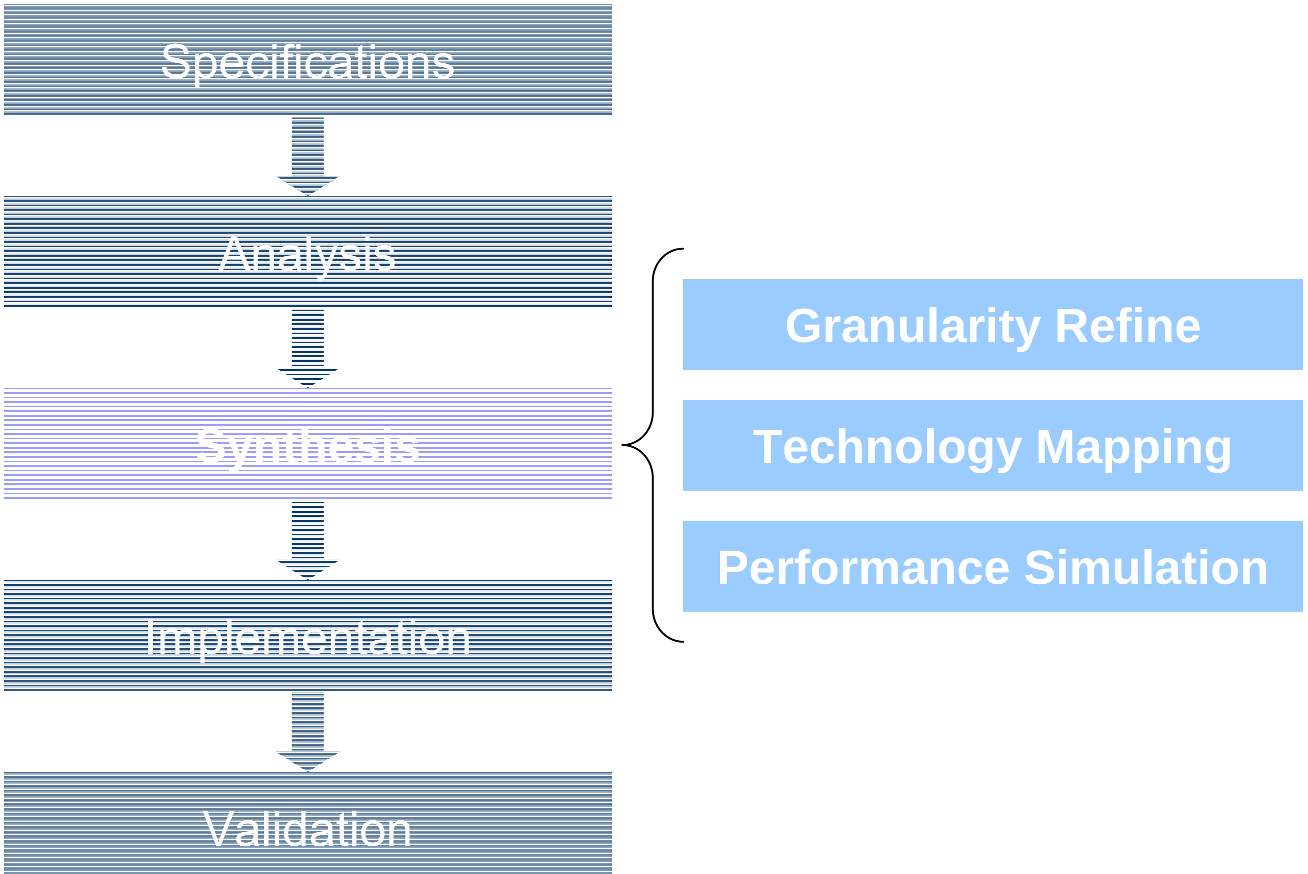
Our HA framework (7/13)

Our Proposal:



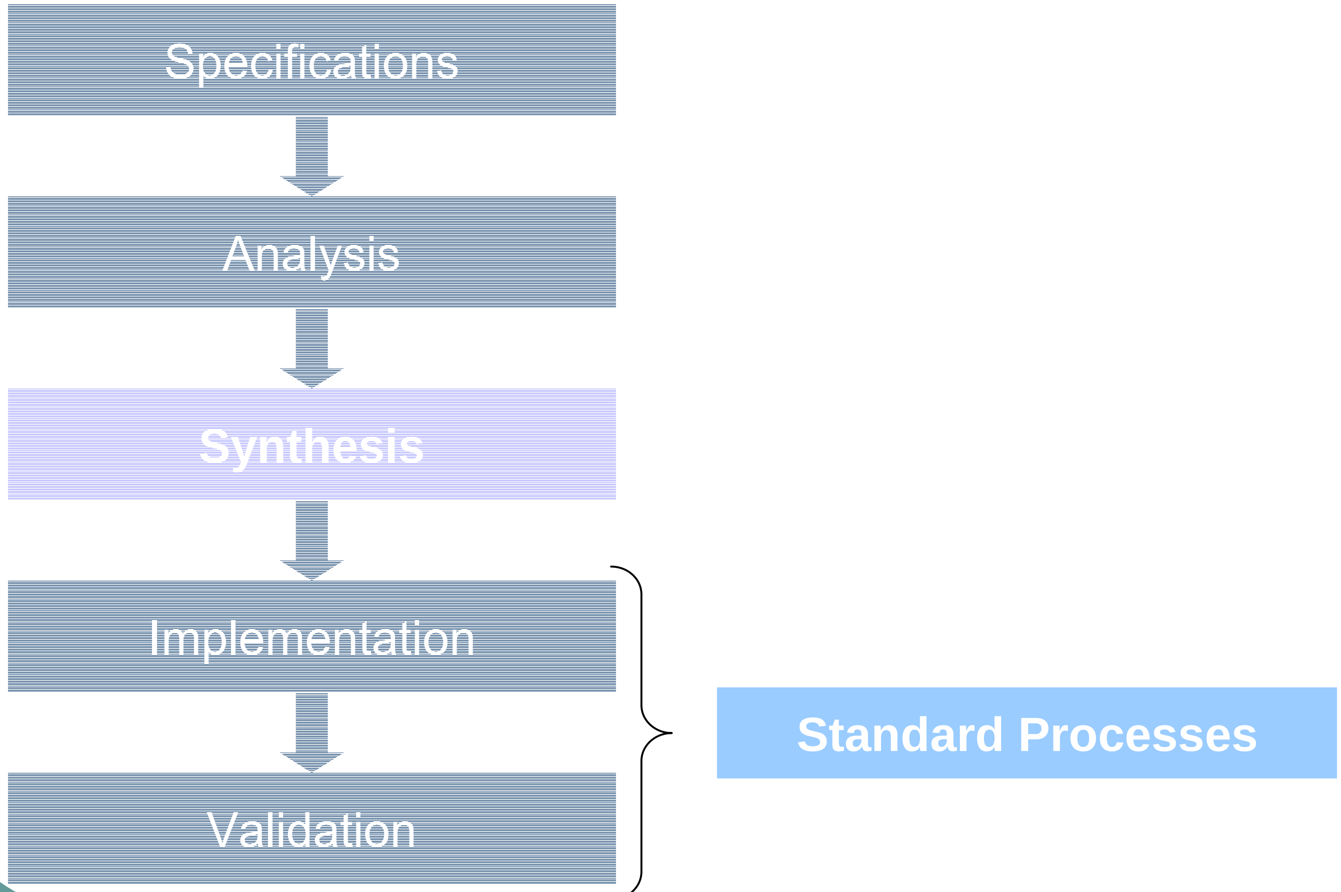
Our HA framework (7/13)

Our Proposal:



Our HA framework (7/13)

Our Proposal:

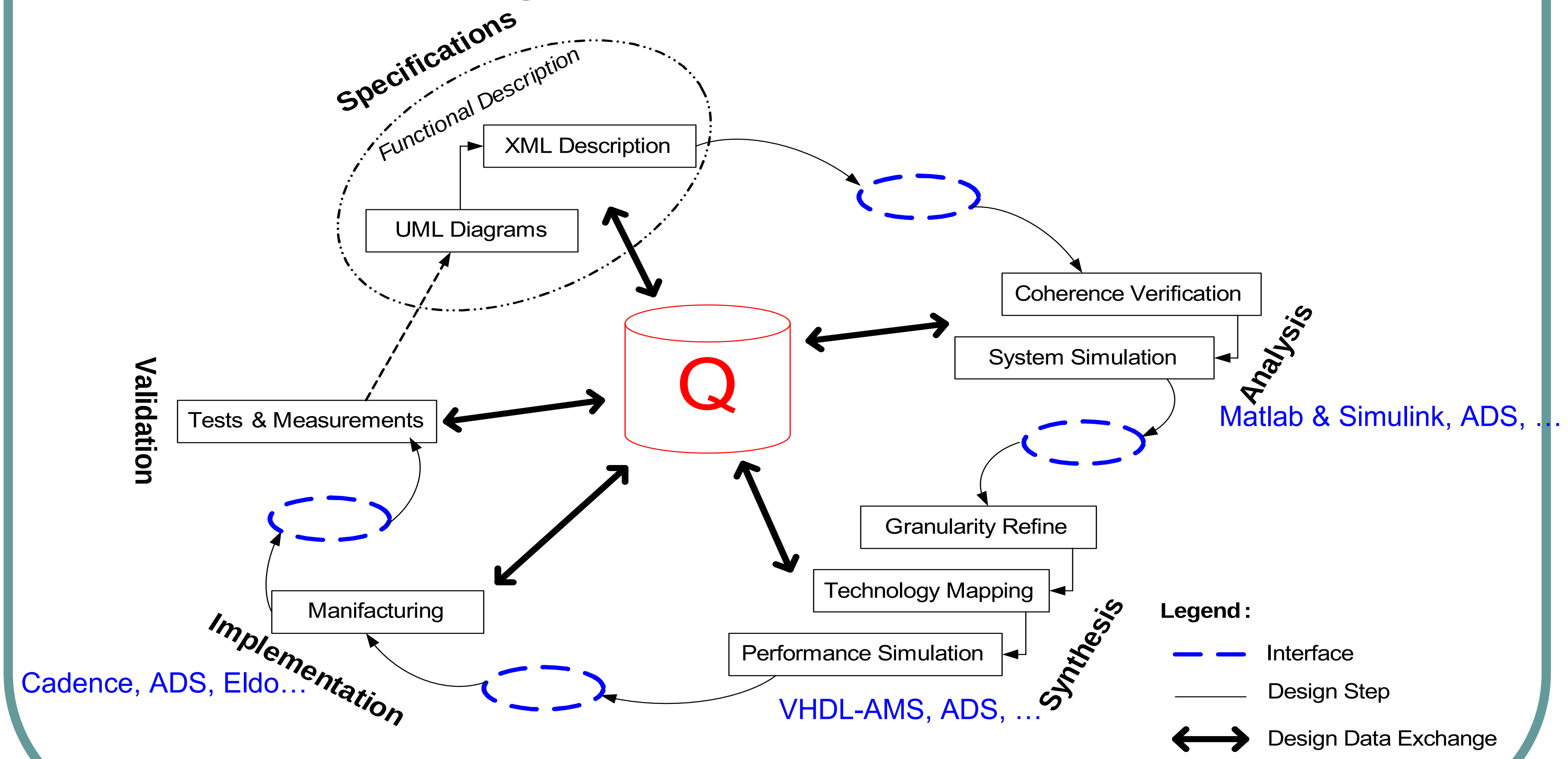


Our HA framework (8/13)

- However, the following issues must be addressed:
  A. The reuse of existent simulation and design tools
  B. The communication between the different design stages: design data flow – transit between steps
- Solutions:
  A. **Issue A:** language and tool-neutral interfaces between the different design stages
  B. **Issue B:** a proposed Q-matrix

Our HA framework (9/13)

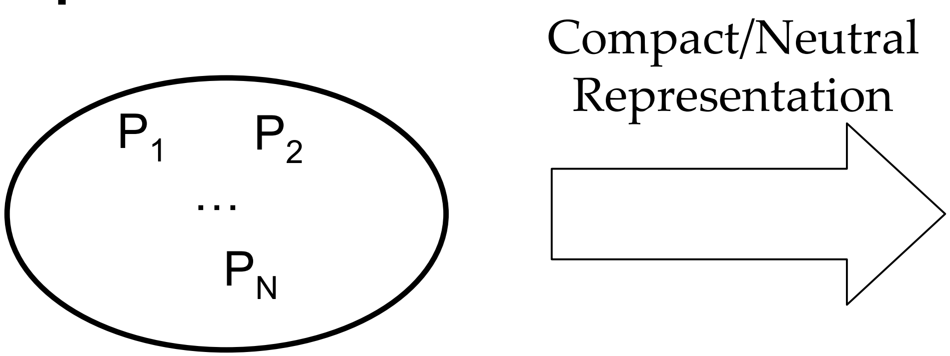
- Newer design scheme [3]:



[3] S. Lafi, A. B. Kouki, J. Belzile, and A. Ghazel, “Towards a coherent framework for automated RF Front-Ends design using hardware abstraction”, IEEE IST 2007, (submitted).

Our HA framework (10/13)

- Now, let's us focusing on the electrical plane !



Minimal set of electrical parameters

$$\begin{bmatrix} Q_{11} & \cdots & Q_{1n} \\ \cdots & \cdots & \cdots \\ Q_{n1} & \cdots & Q_{nn} \end{bmatrix}$$

Q matrix

- We need a generic representation of electrical parameters ➔ *Q-matrix*

Our HA framework (11/13)

- Mathematical definition of Q-matrix [6]

$$Q_{ij} = \frac{b_j \big|_{f=f_j}}{a_i \big|_{f=fi}}$$

Where:

b_j : the reflected wave at the j$^{\text{th}}$ port

a_i : the incident wave at the i$^{\text{th}}$ port

f_i : frequency of the signal entering the i$^{\text{th}}$ port

f_j : frequency of the signal leaving the j$^{\text{th}}$ port

[6] S. Lafi, A. B. Kouki, J. Belzile, and A. Ghazel, “Towards a coherent framework for automated RF Front-Ends design using hardware abstraction”, IEEE IST 2007, (submitted).

Our HA framework (12/13)

- Then [6], $Q \equiv Q\left[T, t, P, F\right]_{N \times N \times N_T \times N_t \times N_P \times N_f}$

- Where:

$T:$	temperature
$t:$	time (aging)
$P:$	power
$F:$	frequency
$N:$	total number of ports
$N_t:$	number of time steps
$N_T:$	number of temperature points
$N_P:$	number of power points
$N_f:$	number of frequency points

[6] S. Lafi, A. B. Kouki, J. Belzile, and A. Ghazel, "Towards a coherent framework for automated RF Front-Ends design using hardware abstraction", IEEE IST 2007, (submitted).

Our HA framework (13/13)

- **Q-matrix:**
  - A multidimensional matrix which captures the electrical parameters of a RF component.
  - Generalize and extend the port definition of the OMG specification
  - Corresponds to a Input/Output and DC/RF port
- **Advantages:**
  - **Generic** (an extended [S] in function of temperature, time, frequency, power, device ports)
  - **Compact**
  - **Complete**

Conclusion (1/3)

- Communications trends issues:
  - Design schemes
  - Abstraction methodologies
- Hardware abstraction:
  - Definition and provision
- Existent approaches:
  - **Baseband:** various elaborated studies
  - **RF:** scarce contributions (OMG's one is the most complete)

Conclusion (2/3)

- Our hardware abstraction framework:
  - Based on the OMG's one
  - Proposes a novel design scheme
  - Resolves the corresponding issues
- New design scheme
  - High-level functional description (Specifications)
  - Coherence verification (Analysis)
  - Granularity refine and Technology mapping (Synthesis)

Conclusion (1/3)

- Issues:
  - Existent simulation and design tools reuse: (**sol.:** interfaces between design stages)
  - Communication between design stages (**sol.:** Q-matrix)
- However a lot of efforts are still needed:
  - Definition of synthesis building blocks
  - Extension of the HA mathematical formalism
  - …

Thank you !

Any Questions, please?